CHAPTER VI

STRUCTURAL DETAILS

6.1 INTRODUCTION

Suppressive shields used for ammunition manufacturing and other hazardous operations require provisions for gaining access to the operation being protected. Personnel must be able to enter the shield to accomplish routine and emergency maintenance and clean-up and other essential operations. An opening of sufficient size must be provided to enable the installation or removal of equipment in realistically large subassemblies. Openings for conveyors and chutes must also be provided and properly configured to prevent excessive pressure and fragments from escaping. Provisions must be made to provide all utilities and satisfy all environmental conditioning needs which may be essential to the operations inside the shield.

Utility penetrations, ventilating and air conditioning ducts, and vacuum lines must not diminish the overall protective capability of the shield. They must not alter the basic mode of structural failure of the suppressive shield and should be small compared to the general size of the shield.

Operations that produce explosive dust may require the use of liners both inside and outside the shield to prevent the accumulation of dust within shield panels. With configurations such as the Group 5 shield, which is primarily designed for use with propellants or pyrotechnic materials, liners must not inhibit the venting characteristics of the shield.

6.2 UTILITY PENETRATIONS

6.2.1 General

Utility penetrations for water, compressed air, and electricity are basic to the manufacturing process of munitions.

Explosive dust and chips are a waste product produced during the manufacture of various munitions. Water is needed for wash down/cooling and deluge operations which safely remove these products. Most deluge lines will be 2 to 2.5-inch diameter industrial hose. Compressed air is needed for the operation of pneumatic tools. A typical requirement might be for 100 psig of dry compressed air at 25 to 30 cubic feet per minute. Electrical power is needed for the prime movers of the manufacturing equipment and peripherals, i.e., motors, air handling units and lights. Depending on the amperage requirements, the size of conduits might vary from 0.5-inch diameter for 120V single phase (lights) to as large as 2 to 3-inch diameter for 440-480 volt three phase service. Penetrations can be routed through the side walls of a shield or through the roof depending on the specific operational requirements.

6.2.2 Design Concept and Rationale

Utility lines passing through suppressive shields are vulnerable to both airblast and fragment hazards. The airblast could push unprotected utility penetrations through the walls of the shield and create secondary fragments. Fragments from an accidental explosion could perforate the thin walls of an unprotected utility pipe and escape from the shield. To eliminate the threat of airblast and fragments, a protective box is used to cover the area where the utility lines pass through the shield wall. The box is configured to rest on the inside surface of the shield and is welded to the shield. The size of the wall penetrations is limited to that required for the utilities, i.e., pipes of 0.5 to 3 inches in diameter. Each pipe is bent at a right angle inside the shield within the protective box. The penetrations of the shield wall are reinforced with a sleeve or box section welded to the shield panel through which the utility line passes. The penetration box is designed to maintain the structural integrity of the shield area penetrated. A typical protective box design is shown in Fig. 6-1. The cover plate thickness is selected to stop the worst case fragment.

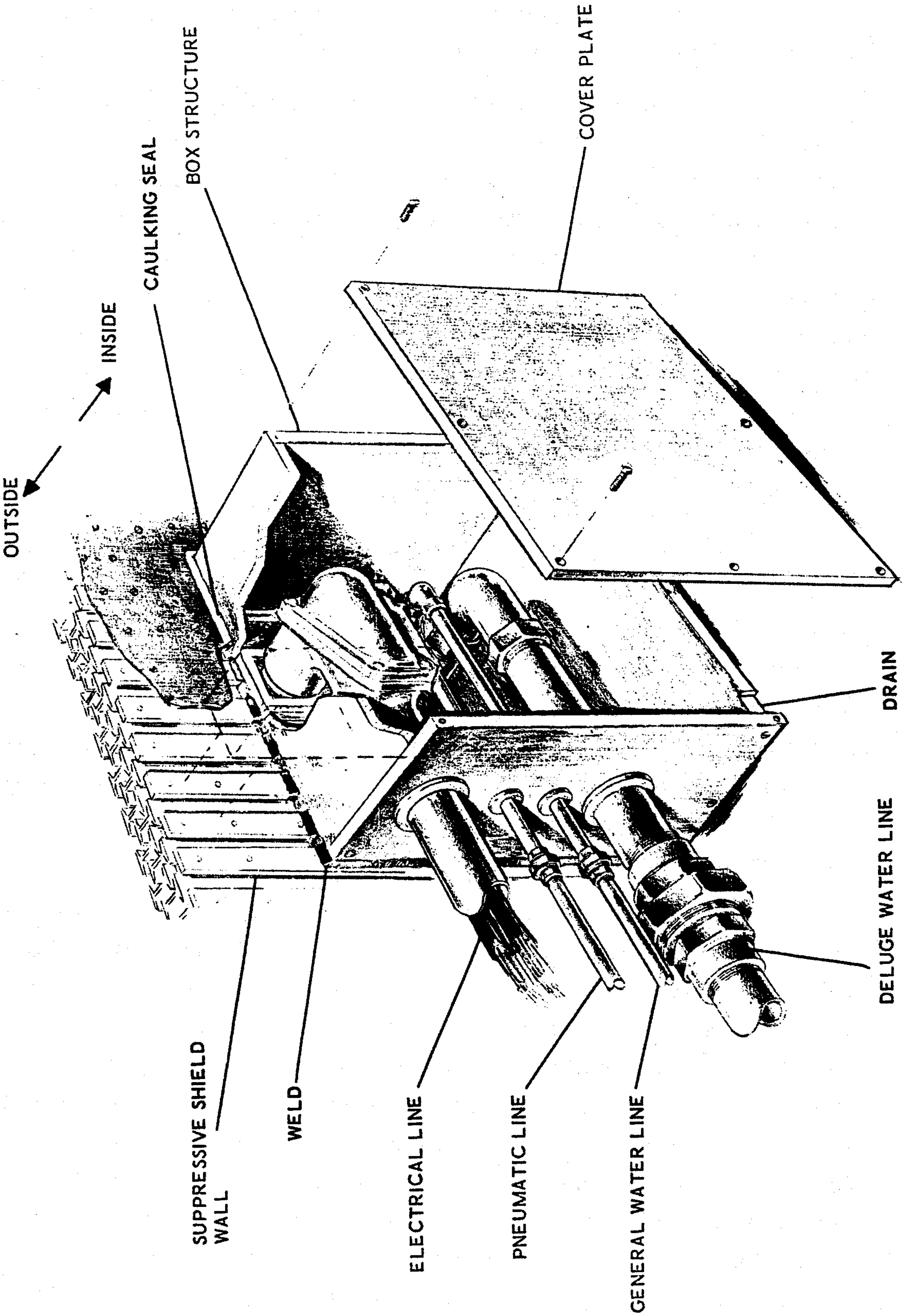


Figure 6-1. Typical Utility Penetration

For the safety approved shields, the minimum cover plate thickness is equal to the nominal steel thickness of the shield wall.

The individual utility lines are arranged with the lowest being deluge water, next highest the general water service, then compressed air and finally the electrical line in the topmost position. This arrangement is recommended to prevent water, leaking from loose or faulty connections, from saturating the electrical line and causing a short circuit. Water accumulation inside the protective box can be avoided by incorporating a suitable drain. Figure 6-1 shows a short slot in the bottom plate which is large enough for drainage yet small enough to prevent fragment entry.

6.2.3 Method of Structural Analysis

The initial step in the design analysis is the determination of the fragment hazard to allow selection of the cover plate thickness. Representative primary fragment hazards for standard ammunitions are listed in Ref. 6-1. If Ref. 6-1 is not available, fragment hazards for standard ammunitions and unusual shapes and combinations can be approximated using the methods presented in Chapter 3. Chapter 3 also provides procedures for computing the material thickness required to prevent fragment perforation.

Once a minimum cover plate thickness has been chosen, the protective box can be designed for the airblast loading. The box consists of a cover plate and four side members. The cover plate is mechanically fastened to the side members, and the complete assembly is welded to the shield panel. The analytical procedure presented here is for the protective box design shown in Fig. 6-1. Alternate designs may be used, provided acceptable analytical procedures are employed to determine the dynamic response of the structural components. To verify the structural integrity of the protective box design, the following analyses must be performed.

- Bending of cover plate
- Buckling of side members

a. Bending of Cover Plate

The cover plate is loaded by the reflected pressure and the quasi-static pressure which causes bending stresses. Procedures for analyzing this member are presented in paragraph 5.5. The ductility ratio must be less than 6 for an acceptable design. Example 6.7.1 demonstrates the method of analysis of a cover plate.

b. Buckling of Side Plates

The side plates of the box structure are assumed to be simply supported along the edges attached to the cover plate and shield panel. Joints connecting side members at the corners of the box are assumed to be clamped. The critical buckling stress is (Ref. 6-2),

$$\sigma_{cr} = \frac{K_b E}{1-\nu^2} \left[\frac{t_s}{b_c}\right]^2 \qquad (6\text{-}1)$$

where K_b depends on the ratio h/b_c and is determined from the following table.

$\frac{h}{b_c}$	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.1	∞
K_b	7.76	6.32	5.80	5.76	6.00	6.32	5.80	5.76	6.00	5.80	5.76	5.73

E = modulus of elasticity, psi

ν = Poissons ratio

h = height of side member, inches

The side plate thickness should be equal to or greater than the nominal steel thickness of the safety approved shields or that computed by the methods of Chapter 3 to prevent fragment perforation.

The compressive stress developed, e.g., in the side members b, by the blast pressure is determined from

$$\sigma_b = \frac{V_B}{b_c t_s} \tag{6-2}$$

where

V_B = dynamic reaction along side b, lbs (see Table 5-4)

The compressive stress from Eq. 6-2 must be less than the critical buckling stress from Eq. 6-1.

c. Effect of Protective Box on Shield Wall Members

The members of shield wall panels are designed without consideration of penetrations and appurtenances. Penetrations (holes) weakens the members; however, pipes and the protective box, because of their weights, attenuate the loads. The protective box serves two functions.

- Protects the pipes
- Redistributes the loads which would have been carried by the weakened members to adjacent members

The longest side plate along the length of the box distributes the load from the box to the panel members as concentrat loads. As shown in Section "A-A", pg. 6-11, at least 80% of the members must be effective in resisting the concentrated loads. Sinc the box cover is relatively flexible compared to the panel members and the concentrated loads are usually away from the midspan of the panel members, the resulting net effect on the panel member from the typical box is negligible.

The shortest side plate along the width of the box, as shown in Section "B-B", pg. 6-11, results in a local overload in the panel member on which it reacts. This overload effect is also considered negligible.

Increase in panel deflection is not expected to be excessive due to the influence of the protective box as the panel members have an inherent built-in safety factor. If the protective box is not located and configured as recommended, serious problems, i.e., excessive deflections, may result. Under special conditions, complex and sophisticated analysis techniques are required such as the use of finite elements or finite differences in the solution of such problems. These techniques are beyond the scope of this handbook.

6.2.4 Location of Utility Penetrations

In rectangular type shields, such as the Group 4, 5 and 81-mm, the utility penetration should be made adjacent to a column or beam at the floor or the ceiling. Figure 6-3 shows a typical installation.

For Group 3 type shields with interlocked I-beam configurations, utility penetrations can be located in the I-beam side walls, the concrete roof, or the foundation. Utility penetrations in the side wall should be located above the floor stiffeners or below roof stiffeners. This procedure is shown in Fig 6-4. Attachment details and engineering drawings are provided in Ref. 6-3.

6.3 VACUUM LINE PENETRATION

6.3.1 Design Requirements

In the process of manufacturing various munitions, explosive dust and chips are generated and must be safely removed as waste products. A common practice is to use a vacuum line for this function. The vacuum line penetration through the shield must prevent the escape of fragments and attenuate the side-on pressure to less than 2.3 psi at any adjacent operator location.

There are three hazards associated with the use of a vacuum line that must be analyzed in the design of a safe waste removal system.

- Detonation of the munition during production operations
- Detonation of airborne dust in the vacuum line
- Detonation of dust sediment in the vacuum line

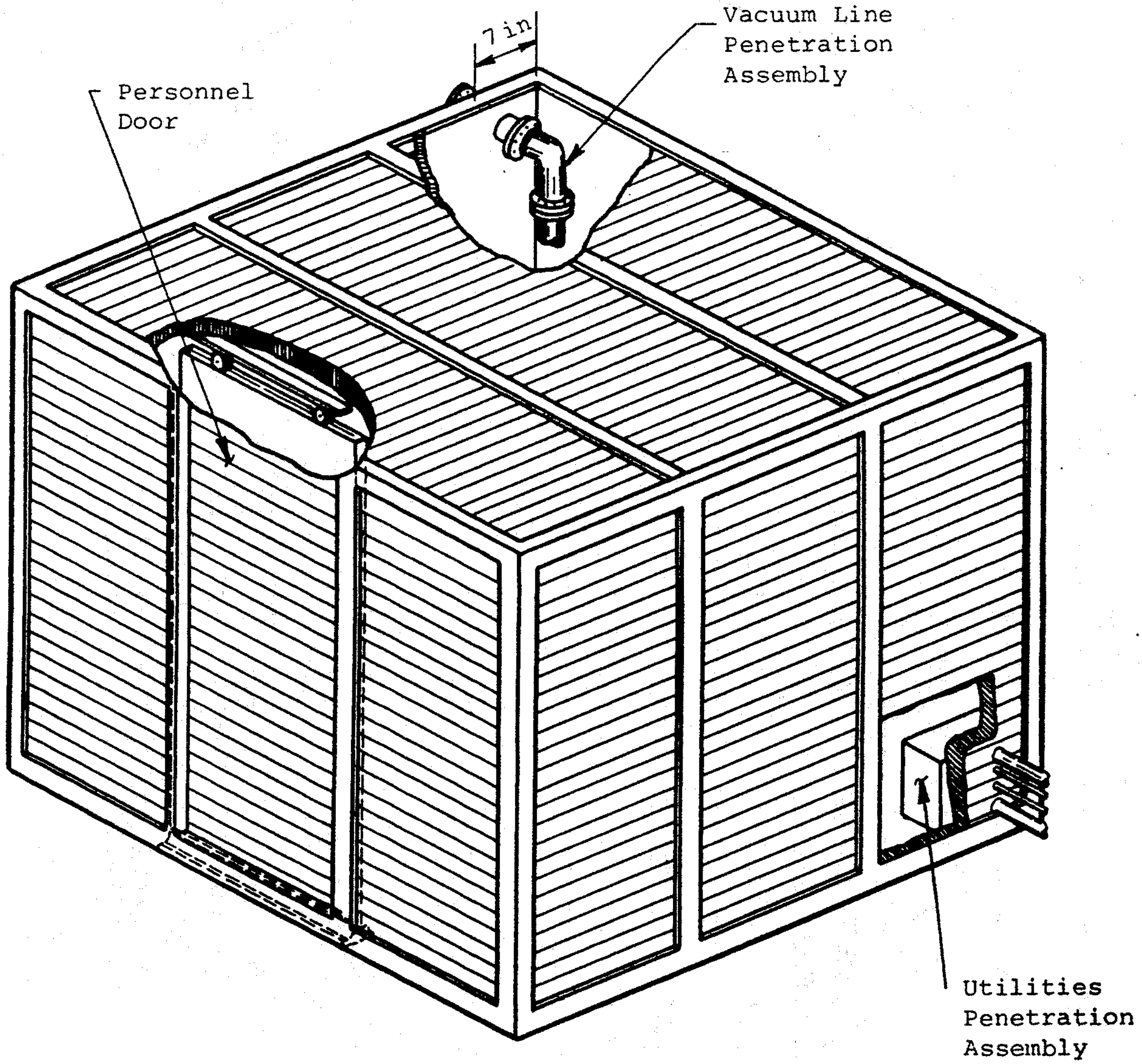


Figure 6-3. Typical Location of Utility Penetration in Shield Groups 4, 5 and 81-mm

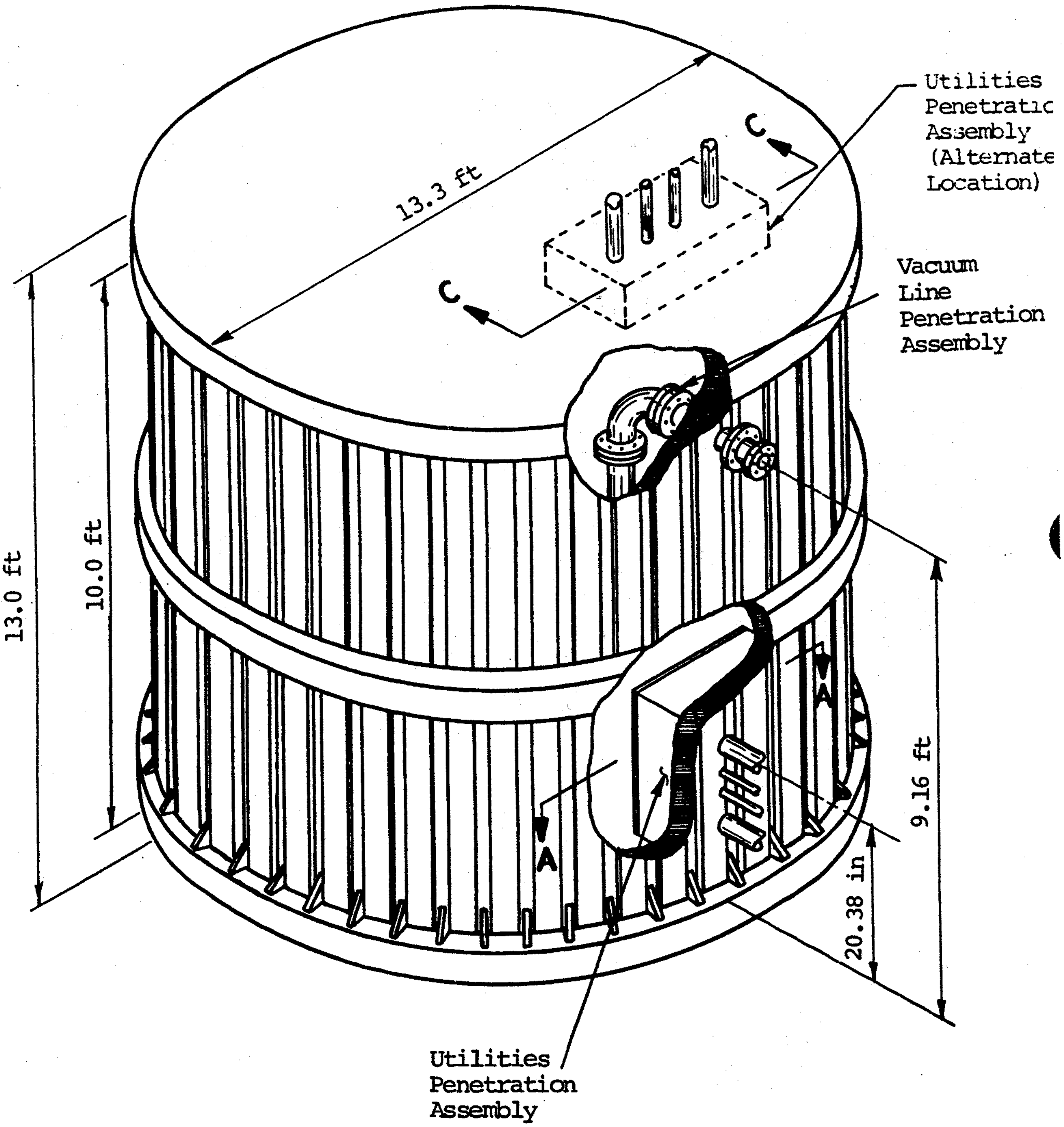
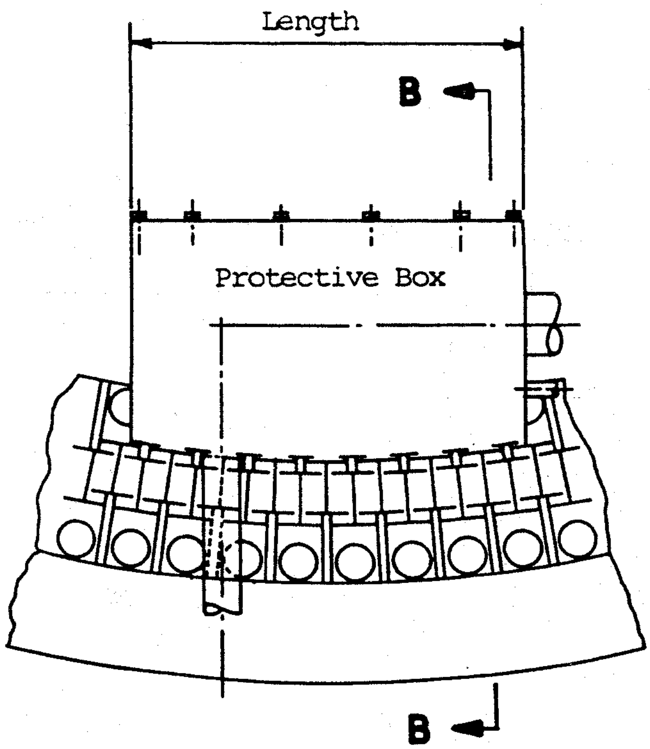
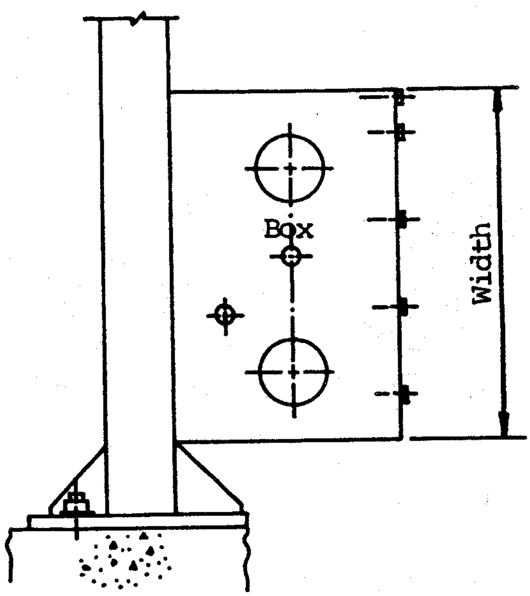


Figure 6-4. Typical Location of Utility Penetrations in Shield Group 3



SECTION A-A



SECTION B-B

Figure 6-4. Typical Location of Utility Penetrations in Shield Group 3 (continued)

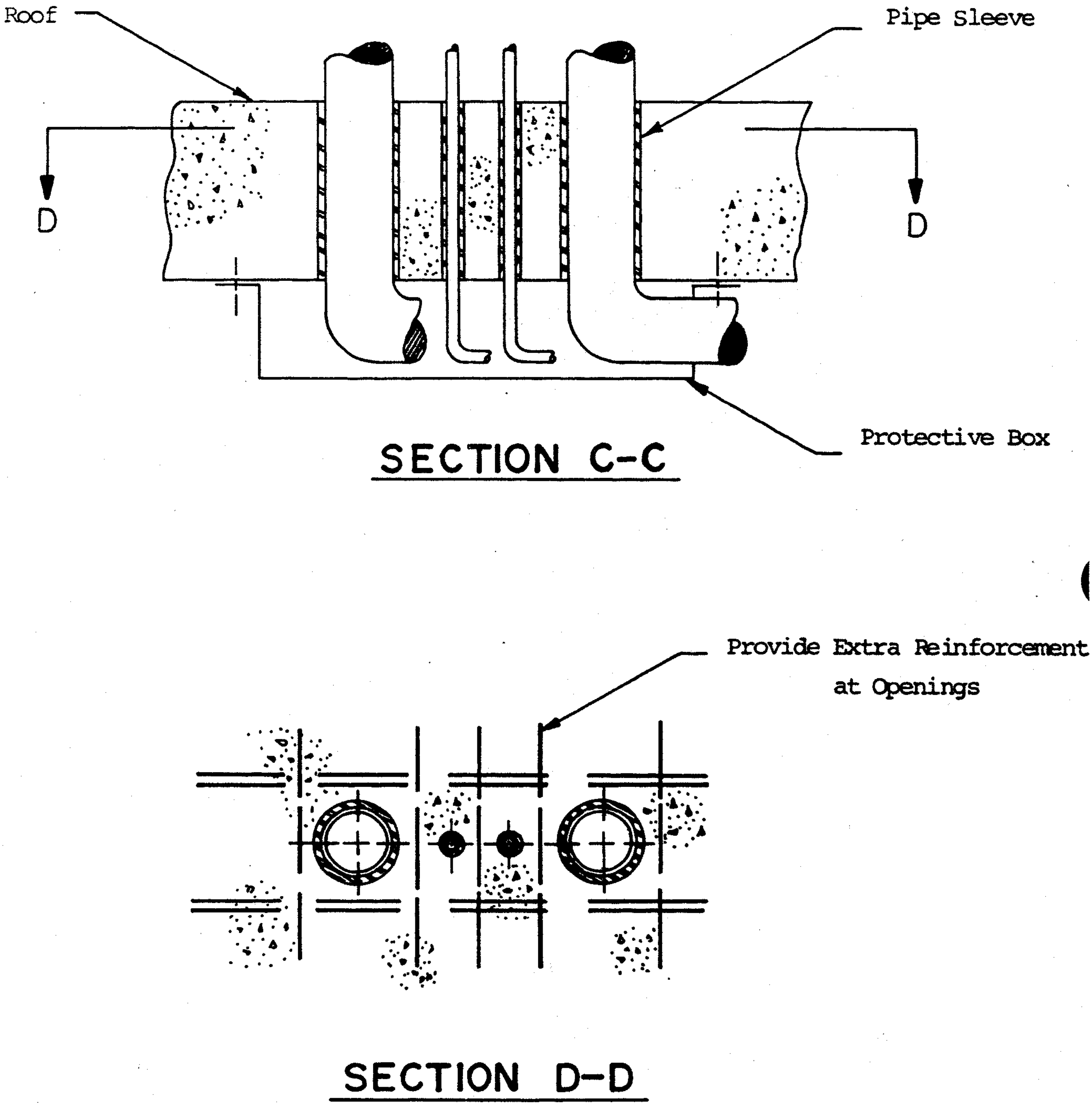


Figure 6-4. Typical Location of Utility Penetrations in Shield Group 3 (continued)

The vacuum line must be designed to allow for periodic disassembly for decontamination. At the shield penetration interface, provisions must be made to prevent the accumulation of dust in joints. All directional changes should be made with a large radius of curvature to preclude dust accumulation.

6.3.2 Design Concept and Rationale

The vacuum line penetration concept used in shield applications is shown penetrating the Group 3 shield in Fig. 6-5. This design satisfies the requirements established in paragraph 6.3.1 and is adaptable to all safety approved shields. Alternate designs were investigated and are described in detail in Ref. 6-4. For special situations when the design concept shown in Fig. 6-5 cannot be used, one of the alternate configurations should be considered. The recommended system consists of a thin-walled aluminum tube (disposal line) encased by a larger diameter aluminum tube which functions as a shield to contain all fragments and airblast effects.

The disposal line is located eccentrically within the shield tube so as to locate explosive dust residue in the approximate center of the shield tube and cause uniform airblast loading. The thickness of the shield tube must be sufficient to defeat fragments from the disposal line. The shielded disposal line extends from the waste disposal area to the shield and terminates just outside the suppressive shield.

The portion of the line which actually passes through and into the shield comprises a number of short, thick-walled steel sections connected by bolted flanges. The bushing in the suppressive shield must be large enough to clear the disposal line flange diameter. The space between the bushing and the disposal line is closed by a pair of split collars which encircle the disposal line and are bolted to the inner and outer faces of the bushing. The split collars support the disposal line where it passes through the shield wall and block the passage of fragments through the clearance space.

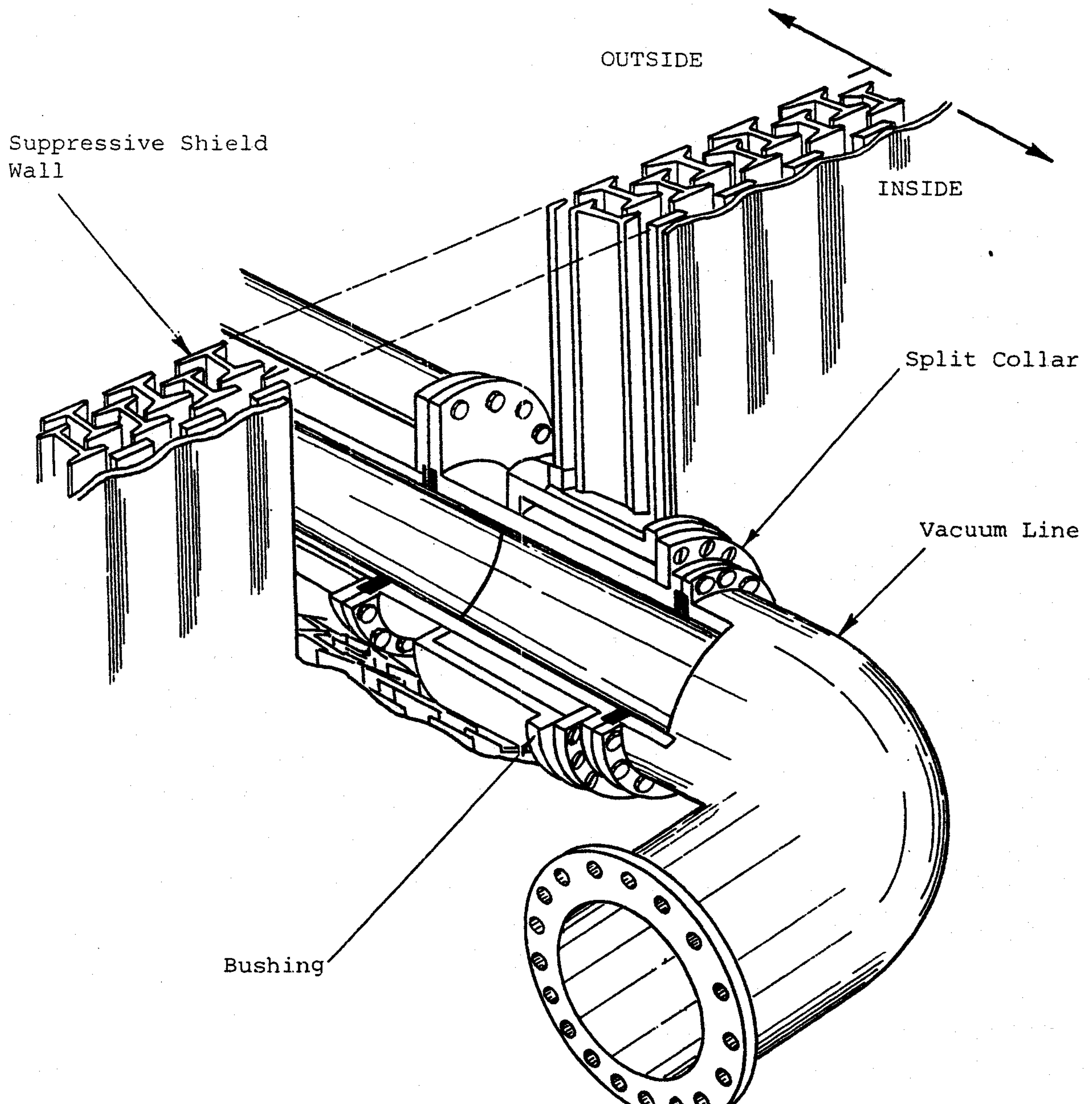


Figure 6-5. Typical Vacuum Line Penetration

Figure 6-6 illustrates the important details of a waste disposal vacuum line penetration through a suppressive shield wall. First, a circular hole is cut through the shield wall and a heavy steel bushing is welded into place. The thickness of this bushing must be sufficient to stop any fragments. All layers of the shield wall are welded to the bushing to retain their structural integrity. This procedure should be incorporated at the time of manufacture of the shield panel. In situations requiring the addition of a vacuum line to an existing suppressive shield, it will be necessary to make the bushing from a number of short tubular sections. The length of each section is at least equal to the spacing between panel layers. Sections are installed one at a time, welding each successive piece to the preceding section and to the appropriate panel layer.

Immediately inside the suppressive shield, the vacuum line contains a 90-degree elbow. This elbow is oriented to prevent the entrance of fragments into the disposal line without at least one ricochet. The elbow has the same inside diameter as the disposal line and is designed with a generous radius of curvature to promote free flow of waste material. The flanged connections are fitted with specially shaped elastomeric compression seals to prevent explosive dust from lodging at the joints. Flanges are bolted together. An alignment pin or pair of witness marks should be provided at each joint to insure that the inner tubes will be properly aligned after assembly. Figure 6-7 illustrates the joint design.

6.3.3 Method of Structural Analysis

a. Detonation of Munition

Two conditions must be satisfied for the waste disposal line to be considered safe under the loads imposed by the explosion of munitions during the manufacturing process.

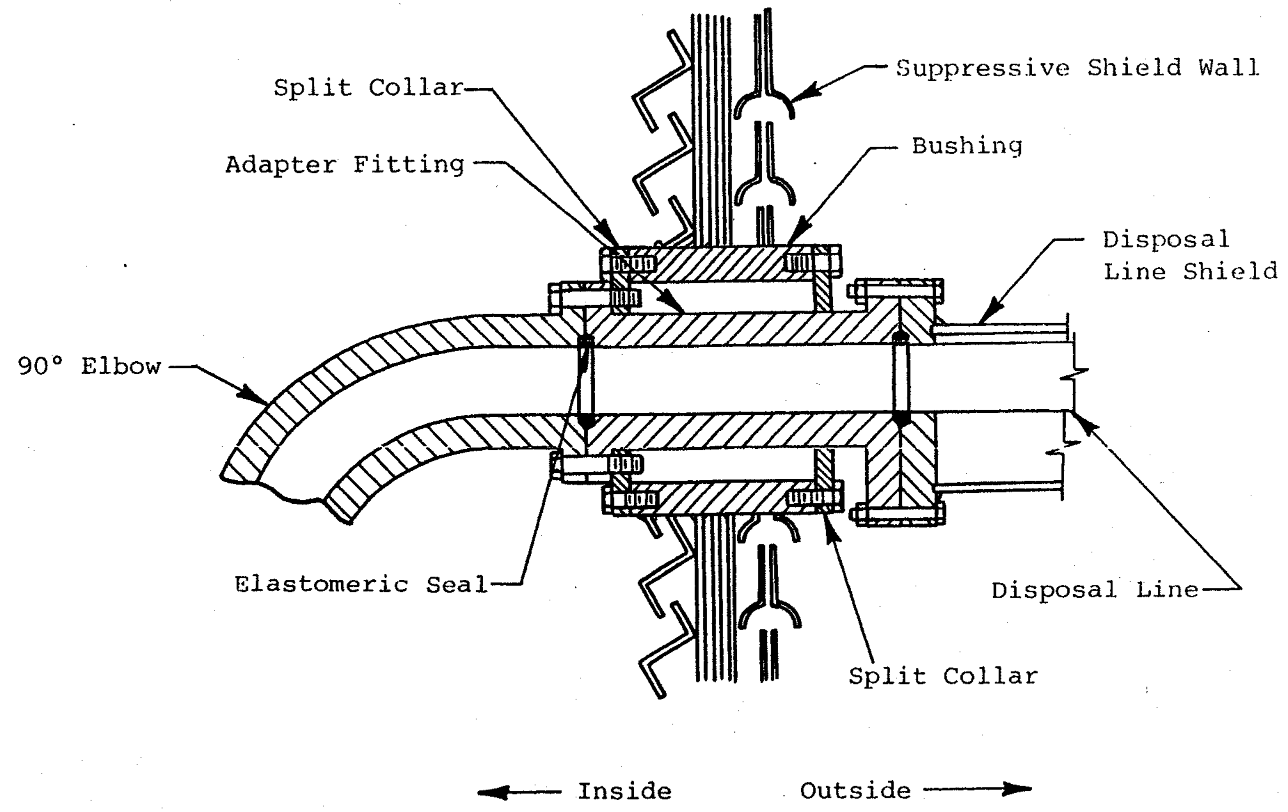


Figure 6-6. Waste Disposal Vacuum Line Entry Into Suppressive Shield

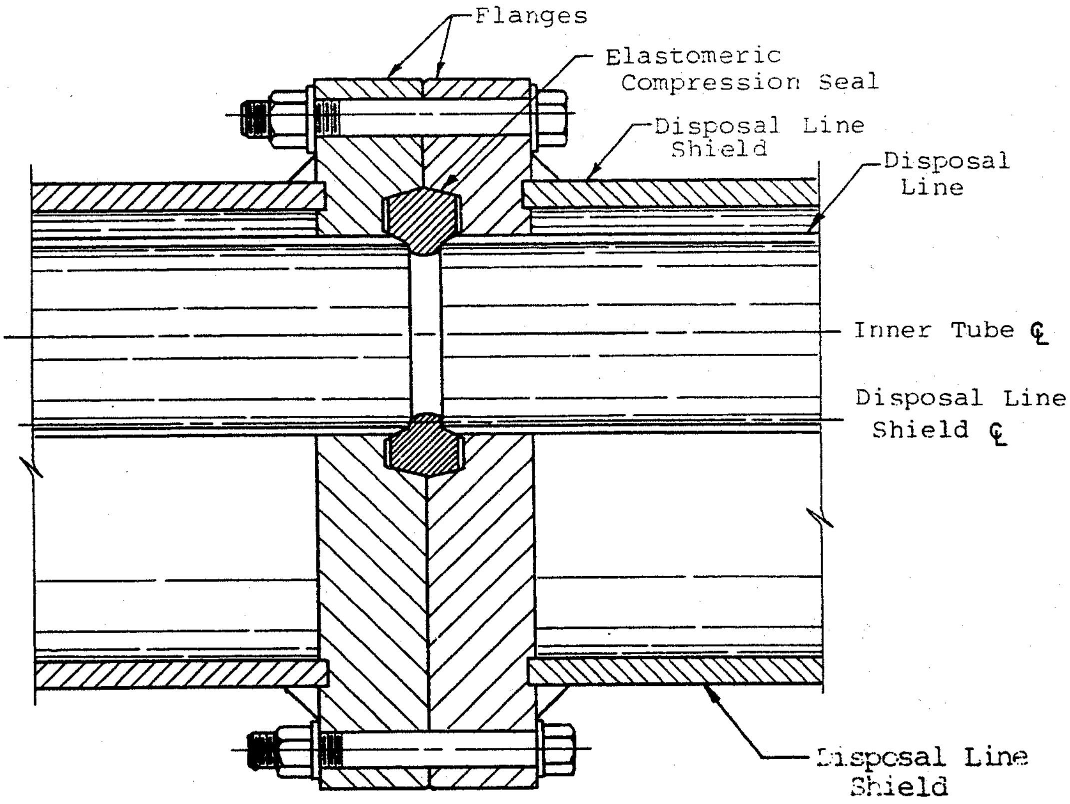


Figure 6-7. Joint Design for the Shielded Disposal Vacuum Line

- The vacuum line/suppressive shield interface must not fail and endanger personnel outside the shield.
- The disposal line shield extending outside the suppressive shield must remain intact in the event that the disposal line itself bursts under a load propagating through it.

Analysis methods for these conditions are presented below.

(1) Vacuum Line/Suppressive Shield Interface

Two modes of failure are possible at the interface between the vacuum line and the suppressive shield wall. The first is a shear failure in the split collar at the location identified as Shear Area 1 in Fig. 6-8. Although the split collar could be subjected to a detailed dynamic analysis, it is a low cost component in the shield. Uncertainties in loading also make any analysis questionable. It is recommended that the required shear strength of the split collar be determined from

$$\tau_S A_{SHC} = A_{VL} f_{dy} \tag{6-3}$$

where

τ_S = shear yield stress for collar material, psi

A_{SHC} = collar area resisting shear, in^2

A_{VL} = cross section area of vacuum line, in^2

f_{dy} = dynamic yield strength of vacuum line material, psi

The shear area should be determined at Shear Area 1 indicated in Fig. 6-8. The split collar should also meet the nominal shield wall thickness criteria for containment of fragments. Since two collars are used at each penetration, their thicknesses should be at least one-half the nominal wall thickness of the suppressive shield wall panel.

A second possible mode of failure is a punching through of the bushing and bushing flange. This would result from a shear failure in the shield wall along the lines marked Shear Area 2 in Fig. 6-8. In order to insure integrity of the penetration, the shield panel cross section area must meet the shear criteria of Eq. 6-3.

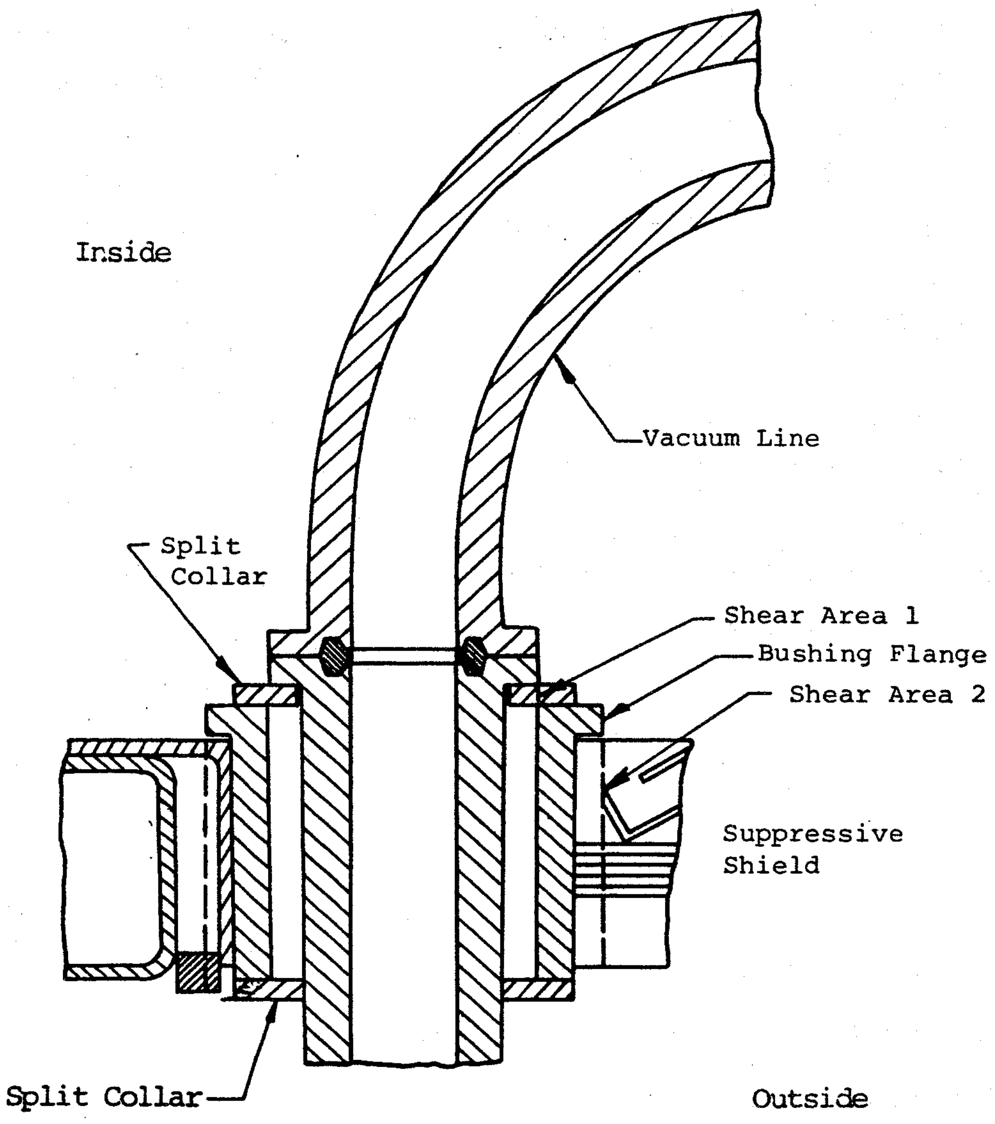


Figure 6-8. Typical Vacuum Line - Suppressive Shield Interface

(2) External Disposal Line Shield

In order to adopt a conservative posture in the analysis, it is assumed that the disposal line does not offer any restraint to the airblast, i.e., the disposal line shield alone must contain the airblast. The dynamic response of the shield tube to the impulsive loading will be affected by the natural period of vibration of the tubing. If the duration of the load is greater than about 5 times the natural period, the load may be considered a dynamically applied long duration load with a dynamic load factor of 2. However, if the duration of the impulse is much less than the natural period of the structure, the load can be considered a pure impulse and the effective stresses and deflections will be increased by a dynamic load factor of less than 2.

The natural period of vibration of the shield tube for internal pressure loading can be obtained from Eq. 5-23 for the natural frequency of a steel hoop.

$$T_N = 2\pi\sqrt{\frac{mR^2}{Et}}$$

where

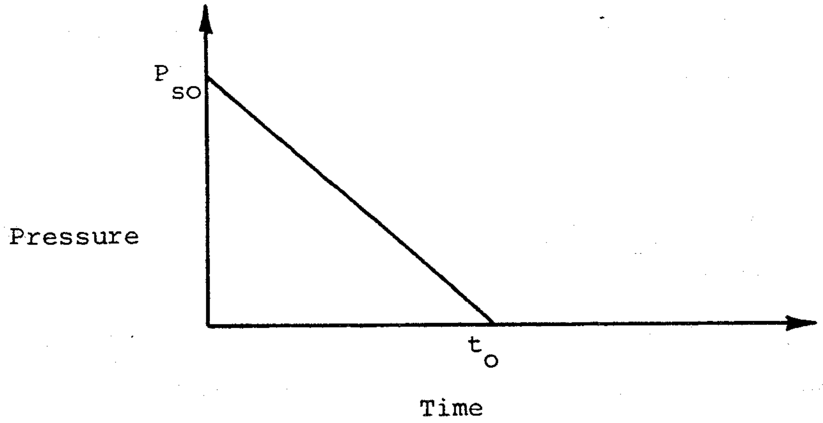
R = average radius, inches

E = modulus of elasticity, psi

t = wall thickness, inches

m = mass per unit surface area of cylinder, $\text{lb-sec}^2/\text{in}^3$

Assume that the impulse load from the air-blast pressure is due to incident overpressure and is triangular as shown below.



From Fig. 3-3, find the peak overpressure, P_{so}, and impulse, i_s, at a scaled distance

$$Z = R/W^{1/3}$$

Select R as the distance to a point just outside of the suppressive shield; W is the TNT equivalent charge weight of the detonating munition.

The positive duration given in Fig. 3-3 is the actual duration of the blast wave and represents an exponential-type decay from the peak pressure. This duration cannot be used in the simplified methods of analysis presented in this chapter. An equivalent duration which conserves the total impulse can be obtained from

$$t_o = \frac{2i_s}{P_{so}} \tag{6-4}$$

Compute the ratio t_o/T_N and, depending on the value of this ratio, use Eq. 5-47, pg. 5-55, to determine the required maximum unit resistance r_m of the shield tube for $\mu = 1$ (elastic case). Then, calculate the tensile stress in the disposal line shield from

$$\sigma = r_m R_i/t \qquad (6\text{-}5)$$

where R_i is the interior radius and t is the thickness of the disposal line shield.

If σ is less than the dynamic yield stress of the material, no further analysis is necessary, because the material remains elastic. In the case of aluminum tubing, there is no increase in yield strength for dynamic loads, i.e., the dynamic yield stress is equal to the static yield stress. If $\sigma > f_{dy}$, the plastic response of the disposal line shield must be examined.

Using the equation for stress in a thin walled tube and the dynamic yield stress of the material, compute the maximum resistance.

$$r_m = f_{dy}t/R_i \qquad (6\text{-}6)$$

Using this r_m and P_{so} and Eq. 5-47, compute a ductility ratio μ.

For a conservative design, the calculated stress should be less than the yield stress of the material ($\sigma < f_{dy}$). However, the tube is satisfactory if the stress is less than the ultimate stress of the material and if

$$\mu = \frac{X_m}{X_e} \leq 6.0$$

b. <u>Response to Airborne Dust Explosion</u>

Detailed data concerning dust explosions for many materials are presented in Ref. 6-5. A portion of the data is presented in Table 6-1. As in the preceding discussion, a conservative approach is taken which assumes that the disposal line shield must withstand the full force of an airborne dust explosion.

The response of the disposal line shield is dependent upon the peak pressure, the ratio of rise time to natural period of the structure and the ratio of the load pulse duration to the natural period of the structure. The preceding paragraph considers a shock wave impulse loading caused by explosion of a munition at the end of the disposal line and propagating through it. In contrast, the load imposed by an airborne dust explosion in the line is a radial pressure load increasing from time zero. Table 6-1 summarizes peak pressures and rate of pressure increase for various types of explosives and a range of dust concentration levels characteristic of disposal lines. If it is assumed that the load increases linearly as a function of time and that the rate of pressure decay from peak is much slower than the rate of increase, Fig. 6-9 may be used to determine the maximum response or required maximum resistance of the disposal line shield.

The loading pulse rise time is

$$t_r = \frac{P_{ro}}{r_p} \tag{6-7}$$

where

P_{ro} = peak overpressure from the explosion, psi

r_p = rate of pressure rise, psi/sec

The first step is to compute the natural period of the disposal line shield using Eq. 5-23. Next, calculate r_m from Eq. 6-6 and the ratio r_m/P_{ro} (equivalent to R_m/B on Fig. 6-9). For this ratio and the t_r/T_N ratio, find the ductility ratio from Fig. 6-9. If designing for a given maximum response, find the required maximum resistance from the ratio R_m/B in Fig. 6-9 and the required line thickness from Eq. 6-6.

Table 6-1

PRESSURE AND PRESSURE INCREASE RATES FOR AIRBORNE DUST EXPLOSIONS (Ref. 6-5)

Explosive Dust	Minimum Explosive Concentration (oz/cu in)	0.20 oz/cu ft		0.50 oz/cu ft		1.00 oz/cu ft	
		Maximum Pressure (psi)	Maximum Rate of Pressure Rise (psi/sec)	Maximum Pressure (psi)	Maximum Rate of Pressure Rise (psi/sec)	Maximum Pressure (psi)	Maximum Rate of Pressure Rise (psi/sec)
Ammonium picrate (comp D)	0.200			74	2,400	141	8,800
Dinitrobernzamide	0.040	73	5,000	94	6,500	118	6,000
Dinitrobenzoic acid	0.050	59	2,300	92	4,300	111	4,100
Nitrostarch	0.070	35	1,600	116	10,000		
Trinitrotoluene (TNT)	0.070	32	700	63	2,100		

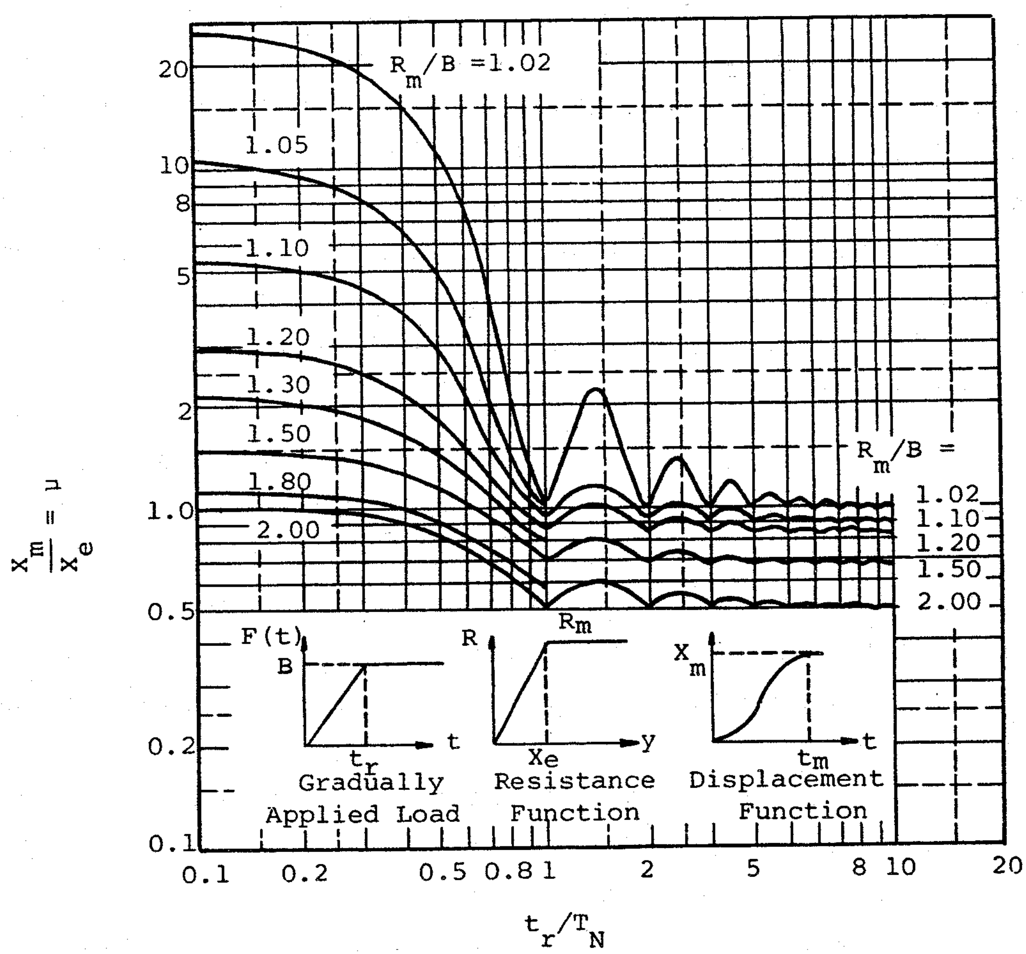


Figure 6-9. Maximum Response of Elasto-Plastic One-Degree Systems (undamped) Due to Constant Force With Finite Rise Time (Ref. 6-6)

Because the disposal line shield is outside of the suppressive shield, safety considerations indicate that the stress should not exceed the yield stress. However, a design in which the ratio $\mu = X_m/X_e \leq 6.0$ is acceptable.

c. Response to Dust Sediment Explosion

A third hazard that must be considered is the possibility of an explosion of dust which has collected on the bottom of the disposal line. The amount of dust sediment that might accumulate in the line depends upon the velocity of air through the line, the size of the dust particles, the shape of the line, etc. Although an accurate analytical determination of the amount of sediment is difficult, an estimate can be made on the basis of inspection of similar facilities and the disposal line cross section shown in Fig. 6-10.

For purposes of analysis, it is assumed that the density of the explosive dust is 0.8 gm/cm^3 and that the sediment behaves like a solid spherical charge of TNT. This is a conservative approach because the dust probably will not be compressed and the airblast parameters computed for a solid charge represent the maximum obtainable. Because the dust sediment explosion is treated as a detonation of solid explosive rather than a relatively mild explosion of airborne dust, the analytical technique proposed is similar to that of paragraph 6.3.3.a. For each inch of line length, the airblast energy imparted to the disposal line shield is equated to the strain energy which can be stored in the shield in order to find the maximum radial deflection.

Using the procedure outlined in Chapter 3, calculate

- The scaled distance $Z = R/W^{1/3}$ for the radius of the disposal line shield (R) and the weight of explosive per inch of line (W)

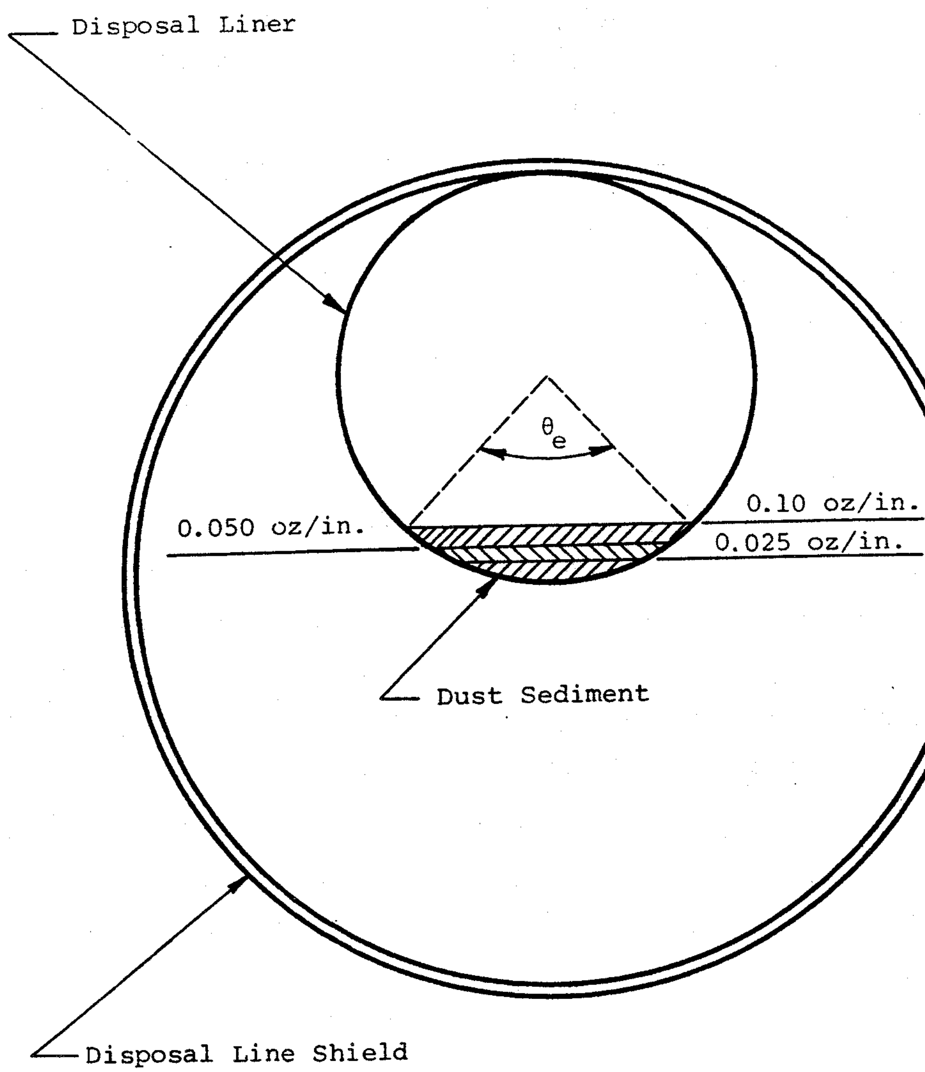


Figure 6-10. Estimate of Dust Sediment on Bottom of Disposal Liner - Shielded Disposal Line Concept

- The pulse duration $t_o = 2i_r/P_r$, where i_r and P_r are the peak reflected impulse and pressure, respectively, from Fig. 3-6.

Once the internal airblast parameters have been established, the design or analysis of the disposal line shield proceeds as described in paragraph 6.3.3.a.(2).

For a safe design, the calculated stress should be less than the yield stress of the material, i.e., $\sigma < f_{dy}$. However, the structure is acceptable if the stress is less than the ultimate stress of the material and if

$$\mu = \frac{X_m}{X_e} \leq 6.0$$

d. <u>Fragment Hazard Analysis</u>

The explosion of dust within the disposal line will propel fragments outward. These fragments must be contained by the disposal line shield. In order to evaluate the fragment hazard, the quantity of metal involved in the process and fragment velocity must be determined.

The weight of metal per unit length of tube subtended by the explosive (see Fig. 6-11) is a function of the depth of the sediment. It can be calculated from

$$W_c = \frac{\rho_m \theta_e}{2}\left[R_o^2 - R_i^2\right] \qquad (6\text{-}8)$$

where

ρ_m = density of tube material, lb/in^3

R_o = tube outside radius, inch

R_i = tube inside radius, inch

θ_e = angle which the explosive subtends (see Fig. 6-11), radians.

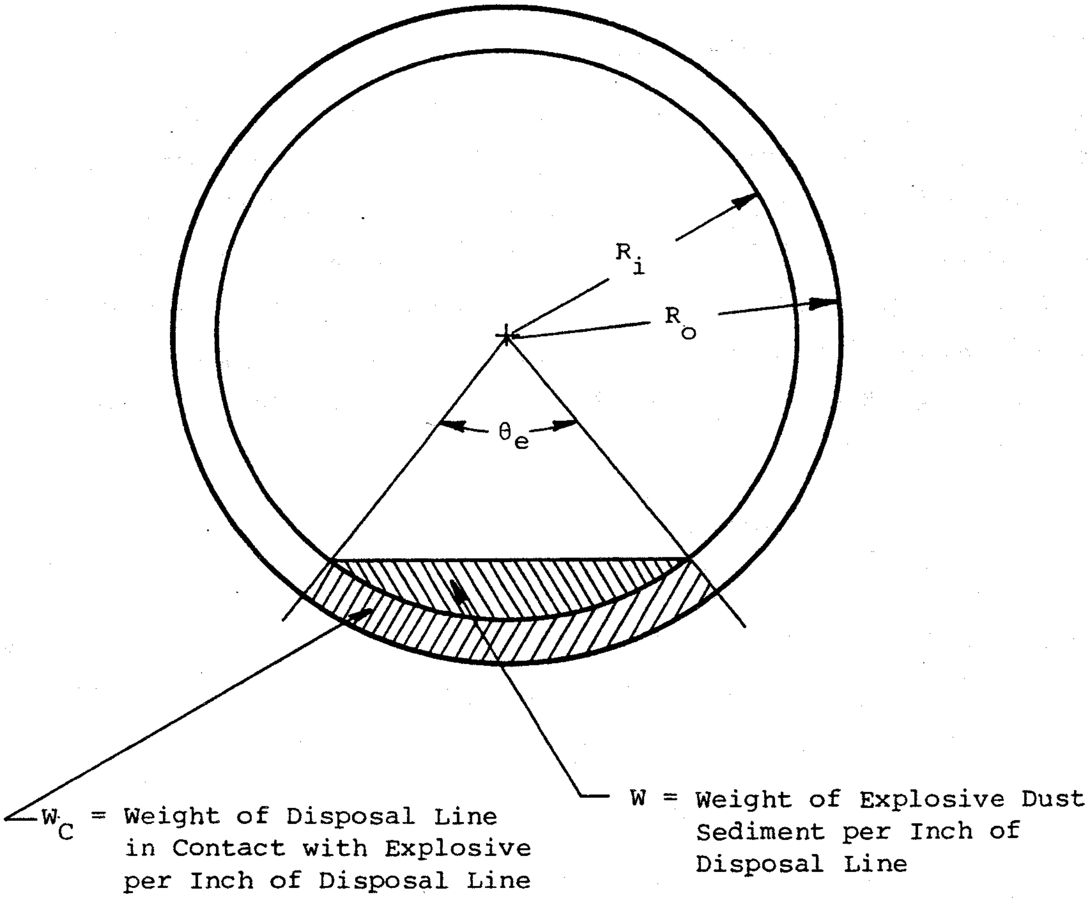


Figure 6-11. Cross Section of Disposal Line With Explosive Dust Sediment

The weight of explosion per unit length is given by

$$W_T = \rho_e \left[\frac{R_i^2(\theta_e - \sin\theta_e)}{2}\right] \tag{6-9}$$

where

W_T = weight of explosive per unit length of tube, oz/in

ρ_e = density of explosive, oz/in^3

The partially filled tube does not meet the criteria for the Gurney cylindrical charge equation for calculating fragment speed since explosive products can flow freely into the unfilled region of the tube during the metal acceleration process. An alternative and more appropriate approach would be to treat the process as an approximation to an open-faced sandwich. In that case, the fragment speed is given by

$$v_o = \sqrt{2E'}\sqrt{\frac{3}{1 + (5W_c/W_T) + 4(W_c/W_T)^2}} \tag{6-10}$$

Fragment velocity predictions were made for the three cases shown in Fig. 6-10. The following constants were assumed

R_i = 0.94 inch

R_o = 1.00 inch

ρ_e = 0.462 oz/in^3

$\sqrt{2E'}$ = 8900 ft/sec

The results of the calculations are

W_T oz/in	W_c oz/in	W_c/W	v_o ft/sec
0.025	0.0853	3.41	1910
0.050	0.1083	2.17	2770
0.100	0.1384	1.38	3880

The minimum fragment velocity required to penetrate a known thickness of material is

$$v_{\ell} = \frac{A_o A_p^m (t_t \sec \theta)^n}{\sqrt{W_s}} \tag{6-11}$$

where

A_o = constant related to material being penetrated, see Table 3-5

A_p = presented area of fragment in the direction of penetration, in^2

t_t = thickness of material being penetrated, inch

θ = angle of impact relative to the normal to the surface of impact

W_s = weight of fragment, lb

m,n = exponents related to material being penetrated, see Table 3-5

Rearranging equation 6-11, the minimum thickness of metal needed to stop a compact fragment impacting normal to the disposal line shield becomes

$$t_t = \left[\frac{v_{\ell}\sqrt{W_s}}{A_o A_p^m}\right]^{1/n} \tag{6-12}$$

The problem which arises in using this method of analysis is the prediction or assumption of fragment properties and the establishment of the various constants and exponents. The constants and exponents presented in Table 3-5 are applicable to the case of compact steel fragments impacting upon mild steel plate. The absence of data for aluminum fragments impacting upon aluminum plate requires the assumption that the constants and exponents of Table 3-5 are applicable to this case also.

This handbook does not include methods for predicting the dimensions of fragments for use in Eqs. 6-11 and 6-12. In the absence of better guidance, it is suggested that the fragments be assumed square in shape with a thickness equal to the thickness, t, of the vacuum line. The dimensions of the square can be taken equal to that portion of the vacuum line circumference in contact with the explosive, i.e.,

$$L = R_i \theta_e \tag{6-13}$$

The weight of the fragment is then given by

$$W_s = \rho_m t L^2 \tag{6-14}$$

where all terms are as previously defined.

It is suggested that the presented area be taken equal to

$$A_p = L^2 \tag{6-15}$$

If the thickness of metal required to stop a fragment computed from Eq. 6-12 is less than that of the vacuum line shield, the shield is satisfactory. If the thickness computed from Eq. 6-12 is larger, a thicker shield is required.

There is some question as to whether a detonation could be propagated in the sediment quantities evaluated above. The maximum thicknesses of explosive in each of the three cases considered are 0.098, 0.154 and 0.248 inch. These are probably less than the critical charge thickness required to sustain the propagation of a detonation under the reduced charge density condition.

6.3.4 Location of Vacuum Line

Depending upon the details of the operation requiring a vacuum line, the location of the penetration could be either in the side walls or ceiling of the shield. The vacuum line penetration is designed to be located in the corner of the Shield Groups 4, 5, and 81-mm adjacent to a beam and column, two beams, or a column and the base of the shield. For the Group 3 shield, the vacuum line penetration is designed to pass through the wall at the web of the I-beam. The vacuum line could also penetrate the concrete foundation or the concrete roof in the Group 3 shield, if required for a special application. Procedures defined in Ref. 6-4 should be used in these situations. Figures 6-3 and 6-4 show typical installations of the vacuum line.

6.4 ENVIRONMENT CONDITIONING PENETRATION

6.4.1 Design Concept and Rationale

Certain hazardous operations require special control of air temperature and humidity and require periodic air changes inside a suppressive shield. Since operating personnel are not present inside a shield during operation, it is not necessary to meet the air change requirements of OSHA for occupied spaces.

The air can be introduced inside the suppressive shield in several ways. The method selected will depend upon the air conditioning requirements for a particular operation. It may be sufficient to use conditioned air around the outside of the shield and have it leak through to the inside via the spaces around shield penetrations such as personnel and product doors. Where the air flow requirements cannot be satisfied in this manner, inlet ducts of sufficient thickness to withstand the airblast loading and configured to prevent fragment escape are required. The equipment which supplies air to the shield must be located so that airblast effects will not endanger personnel in the surrounding area. The inlet duct penetration design is the same as the vacuum line penetration. Design procedures provided in paragraph 6.3 should be applied.

Air is removed from the suppressive shield by a duct penetrating the shield roof. This duct or stack must extend beyond the roof of the building housing the suppressive shield and be of sufficient height to prevent excessive airblast pressures from acting on the building roof. This concept is shown in Fig. 6-12. In operations which generate explosive dust, filters should be located in the stack. Operations having a waste disposal (vacuum line) system may not require an alternate method for exhausting air, provided sufficient air is exhausted from the shield through the disposal system.

6.4.2 Design Procedure

The design procedure for the inlet duct penetration has been presented previously in paragraph 6.3. A design procedure for the exit duct/stack is presented below.

The first step is to determine the required number of air changes per unit of time for the operation being shielded. In the absence of other specific requirements, assume that two complete air changes per hour will be provided. This is consistent with industrial practice for enclosures which are not occupied during operations.

The exhaust area required is a function of the air flow rate and velocity

$$A_{ex} = \frac{Q}{v_a}$$

where

Q = air flow rate, ft^3/min
$= V \times N_a$

and

V = shield internal volume, ft^3

N_a = number of air changes per minute

v_a = air flow velocity, ft/min

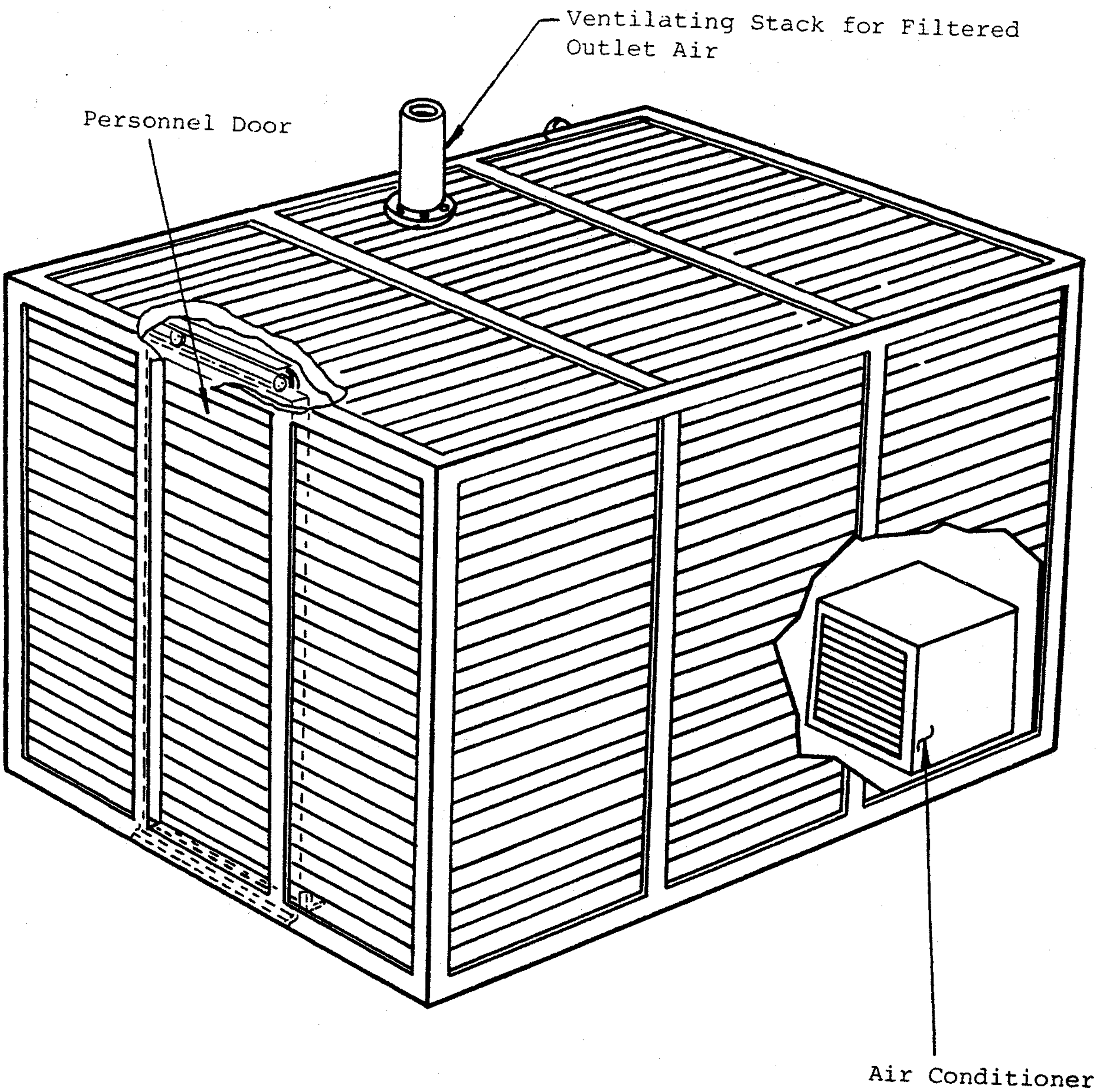


Figure 6-12. Typical Environmental Conditioning Penetration

There are no experimental data pertaining to the airblast pressure field outside a stack emanating from the roof of a suppressive structure. Tests have been performed and a predictive model developed for four walled cubicles with a square vent hole in the roof (Ref. 6-7). By making several assumptions, the model shown in Fig. 6-13 can be applied to an exhaust stack. It is assumed that no pressure decay occurs in the stack and that the pressure decay outside the stack is the same as that occurring outside the four walled vented cubicle of Fig. 6-13. The incident pressure outside the stack is determined from

$$P_s = 290\left[\frac{A_{ex}}{V^{2/3}}\right]^{0.401}\left[\frac{W^{1/3}}{R}\right]^{1.496} \tag{6-16}$$

where

R = horizontal distance from stack exit to point of interest, ft

W = charge weight, lb

Equation 6-16 is a curve fit to data and is applicable to the conditions within the range of test parameters, i.e.,

$$0.063 \le W/V \le 0.375 \text{ lb/ft}^3$$
$$0.0198 \le A/V^{2/3} \le 1.000$$
$$1.59 \le R/W^{1/3} \le 63.0 \text{ ft/lb}^{1/3}$$

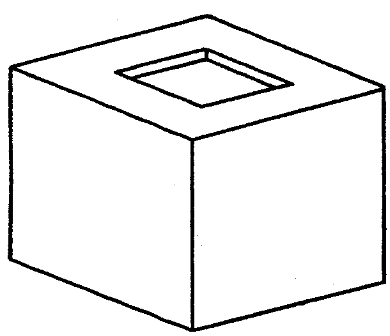


Figure 6-13. Cubicle with Partial Roof

Equation 6-16 was used to develop the design curves shown in Fig. 6-14. The dashed lines on Fig. 6-14 represent approximately the above limits of experimental data. These curves can be used to size a vent to limit peak pressure at a given distance or to predict what the peak pressure will be for a given size vent.

It is important to note that Eq. 6-16 and Fig. 6-14 are for predicting the pressures outside a cubicle on a horizontal plane located at the elevation of the vent area. If the horizontal plane of interest lies below the elevation of the vent area, pressures at points located within several cubicle heights are less than those given by Fig. 6-14 and the differences increase with W/V. Reference 6-7 discusses a semi-empirical method for modifying the pressures obtained from Eq. 6-16 and Fig. 6-14 when the planes of interest and vent area are not at the same elevation. The procedure was proposed for open-top, four-wall cubicles and its application to vent openings is uncertain. It is suggested that the procedure be used if the point of interest is closer than 3 times the difference in elevation between the vent opening and the plane of interest. An alternative is to take R equal to the radial distance from the vent opening to the point of interest.

Stresses in the stack can be obtained by first predicting the peak overpressure and duration at a point just outside of the suppressive shield wall or roof. Figure 3-3 is applicable. Next compute the natural period of vibration of the stack from Eq. 5-23 and follow the procedure described in paragraph 6.3.3.a.(2) to obtain maximum stresses and displacements.

6.5 ACCESS PENETRATIONS

6.5.1 Requirements

In the munition plant environment, suppressive shields are designed to protect category III or IV hazardous operations as defined in Table 1-1, Pg. 1-7. Remote operation is required,

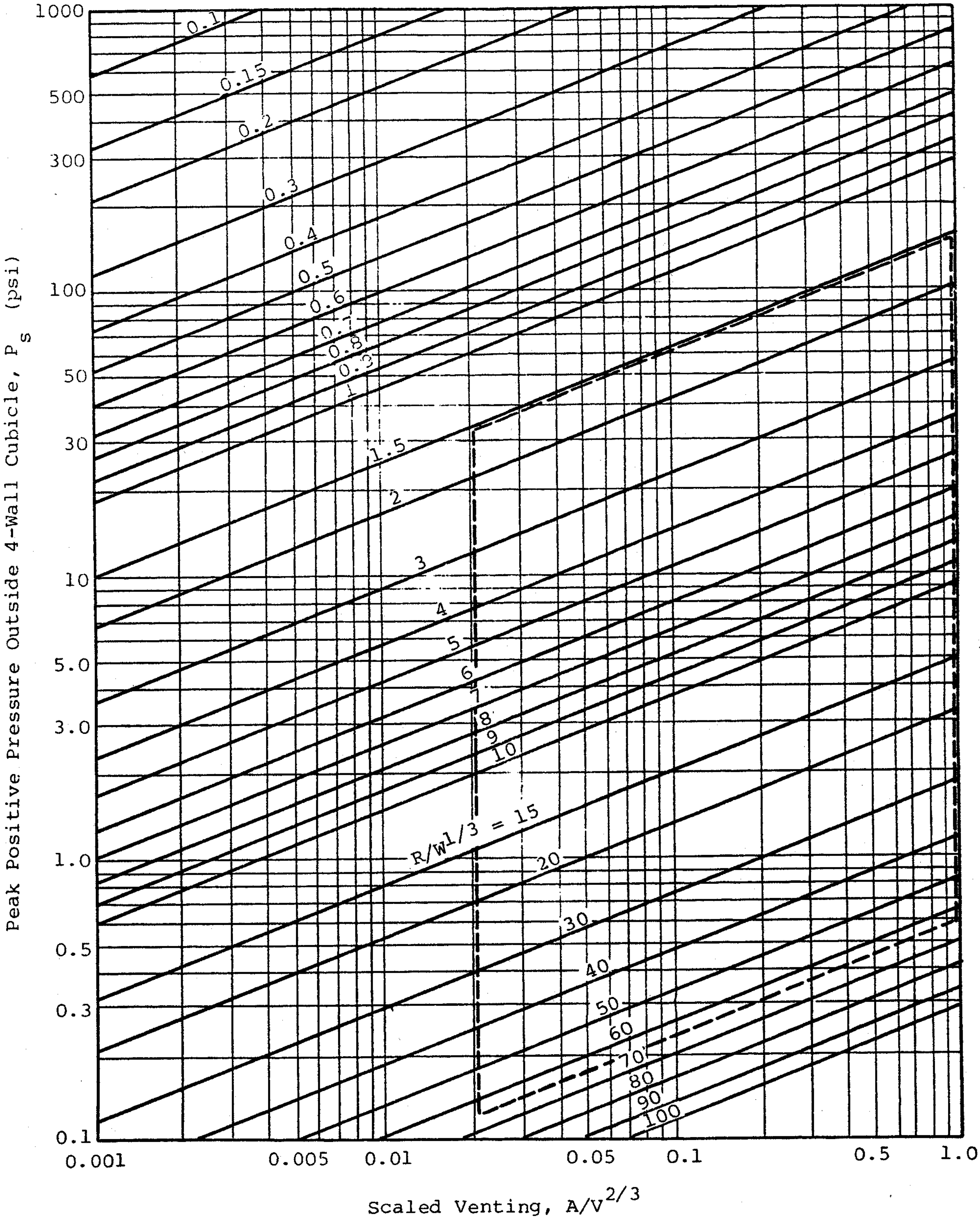


Figure 6-14. Design Chart for Vent Area Required to Limit Pressures at Any Range Outside a 4-Wall Cubicle

and personnel will not be inside the shield during operation. However, access to the equipment must be provided to allow for maintenance, repair, and inspection as required. Personnel doors which satisfy the above requirements have been designed for each of the safety approved shields. These doors also provide large openings to enable most equipment to be installed or removed in realistically large subassemblies. Exits from these shields have not been designed in accordance with Ref. 6-8, since no personnel are in the shield during the operation. The door remains open for conditions requiring personnel access.

Access is also required for munition components, explosives and assembled munitions to pass through the suppressive shield. In the case of conveyor transporting systems, consideration must be given to the proper pass-through of the conveyor. Requirements for this type of access depend on the configuration of the munition product, transporting pallets and conveyors as well as production rates and other factors unique to each operation. For these reasons, definition of specific design requirements is not possible. Design of a rotary type door which allows pass-through of projectiles is discussed in paragraph 6.5.4.

6.5.2 Safety Considerations

All access doors are designed to provide the same level of protection as the suppressive shield, i.e., attenuation of airblast pressure and fireball and containment of all fragments.

Safety considerations require an interlock system on personnel access doors to prevent a hazardous operation from being conducted with a door open. The door should be fitted with two limit switches such that both the switches are activated when the door is closed. Moreover, the interlock circuit should be designed to indicate the closure of both switches sequentially within a finite time interval of each other. This feature prevents tampering of the type where one switch is taped closed and the other can be used to simulate door opening and closing by manual operation.

6.5.3 Personnel Door

a. Design Concepts

Three different types of doors have been developed for use in suppressive shields: sliding, hinged, and double leaf. The hinged door was designed to swing inward. This undesirable feature reduces the useable space inside the shield. A sliding door is preferred for personnel access to munition operations. Figure 6-15 illustrates a typical sliding door. This type door is used with the Group 4, 5 and Milan 81-mm shields. The sliding door consists of an entire shield panel suspended from a monorail system. The panel is inside the shield and is not rigidly attached to the column members. Special consideration was given to the air gap between the door panel and the column to assure that excessive pressure leakage would not occur and that fragments could not pass through the gap.

The cylindrical Group 3 shield contains a two-leaf door, hinged at each side. It swings inward as shown in Fig. A-3. The door is curved to match the shield wall contour and is fabricated from S5 x 10 I-beams. Pressure loading restraint is provided by the door bearing on the external support rings of the shield at the top and bottom of the door. An external latch provides restraint during rebound of the door.

b. Design Procedure

(1) Sliding Door

The shield panel in the location selected for the sliding door is replaced by the door panel. The door panel is of the same construction as the other shield panels;

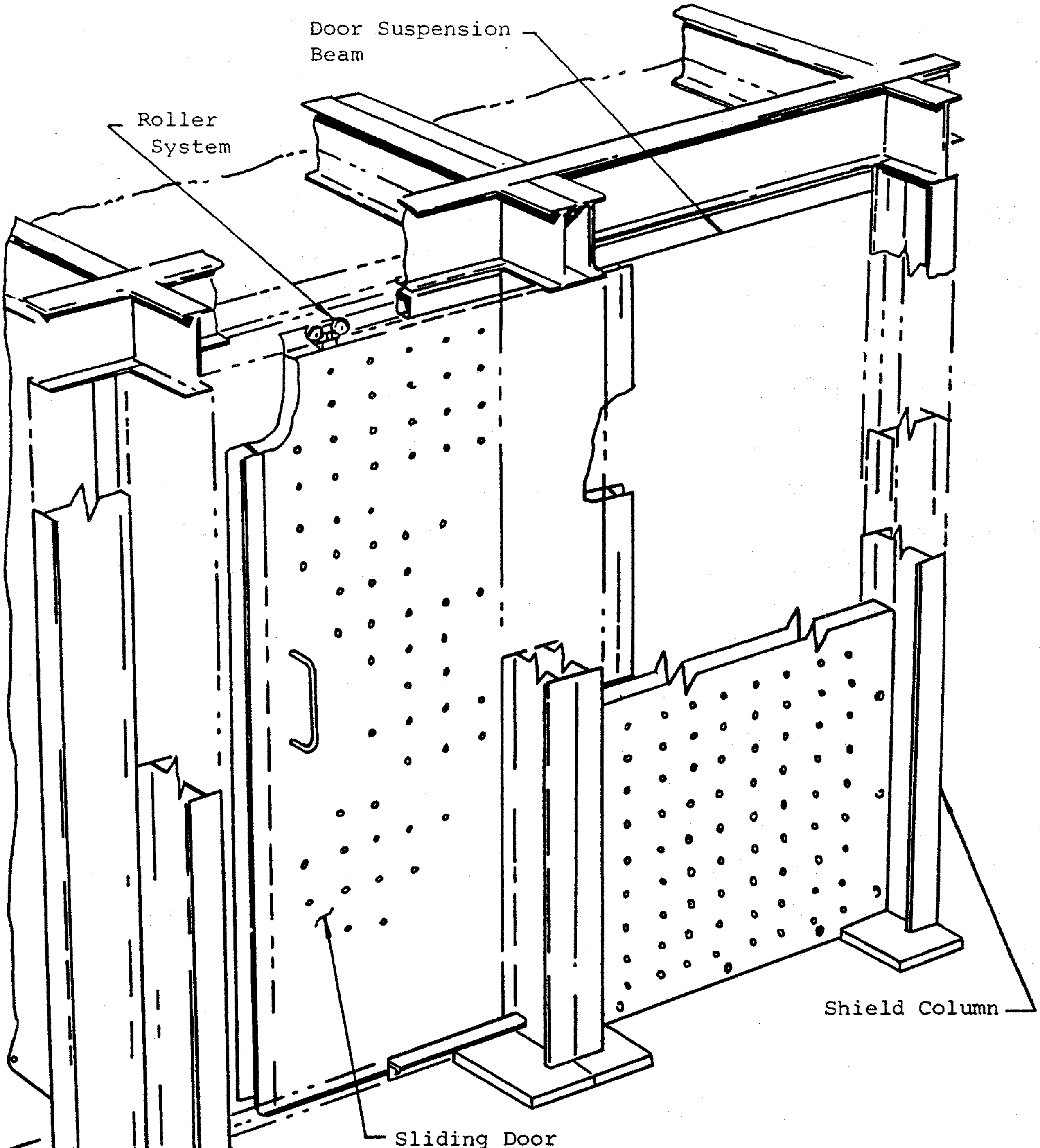


Figure 6-15. Sliding Personnel Door

therefore, it provides the same airblast and fireball attenuation and fragment containment capability. A commercial track and trolley system is selected based on the door weight. Standard assembly procedures are followed for installation of the track and trolley system.

(2) Leaf Door

The beams comprising the leaf door are designed as simply supported elements spanning the vertical dimension of the door. They are heavier sections than those in the Group 3 shield wall because of the single layer and loss of continuity at the supports.

6.5.4 Product Door

a. Design Concept

Only one type of product door has been developed conceptually for use in suppressive shields. It is the rotary, three lobed configuration shown in Fig. 6-16. The design procedure for this door is described to illustrate the type of analysis required. It can be used as a guide for analysis of similar alternate design concepts for product doors.

b. Safety Considerations

The airblast will most severely load the rotating product door when the munition opening is coincident with the pocket in the rotary door. A nonoverriding clutch prevents the door from counterrotating. The angular impulsive load is

$$T_i = i_r A_d r_d \tag{6-17}$$

where

i_r = reflected impulse, psi-sec

A_d = door area, in^2

r_d = radius from center of impulse load to center of door rotation, inches

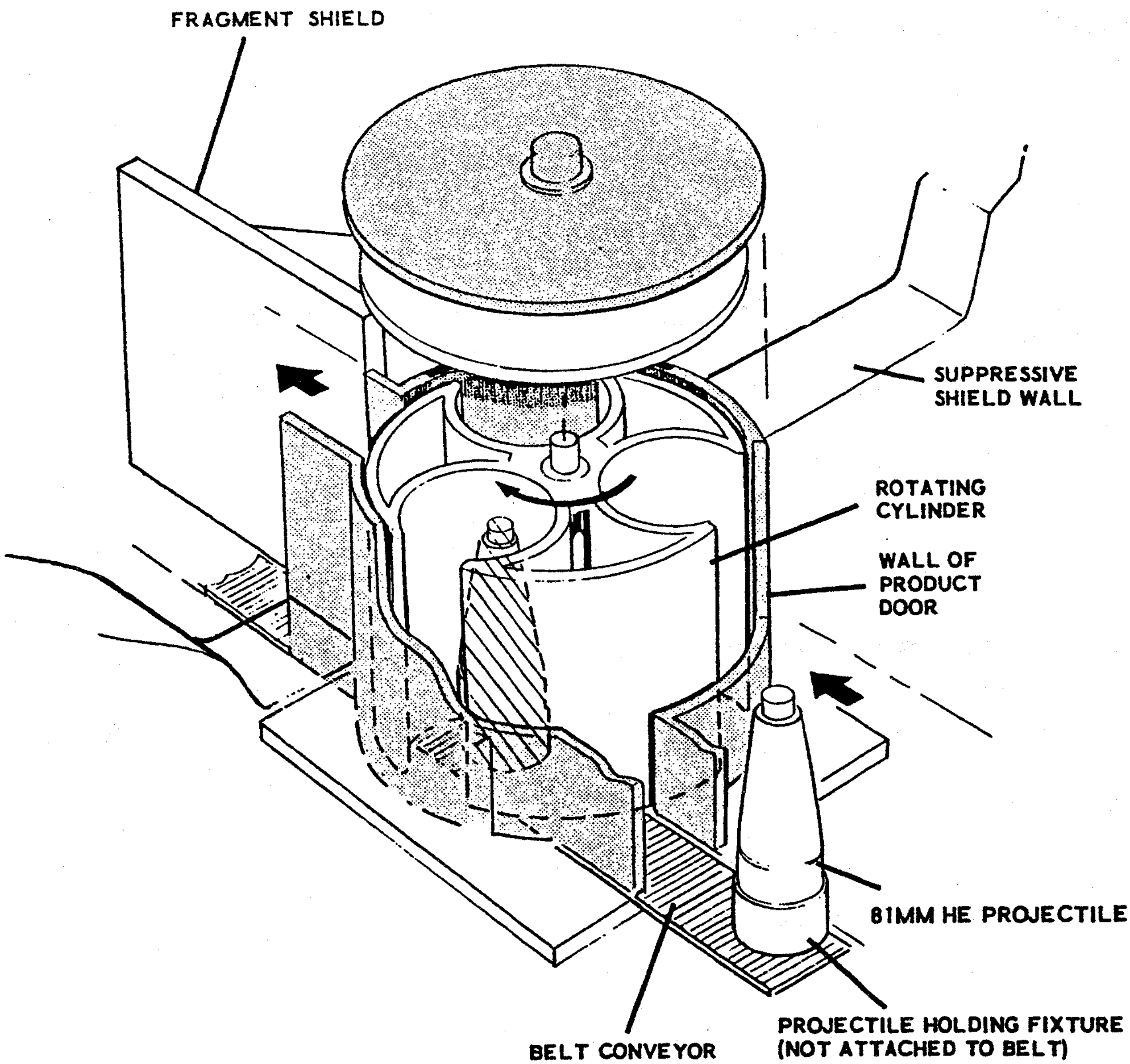


Figure 6-16. Rotating Product Door

Assuming the product door to be initially at rest, the rotational velocity imparted to the door is given by (Ref. 6-9)

$$\omega = \frac{T_i}{I_m} \qquad (6\text{-}18)$$

where

ω = angular velocity, rad/sec

I_m = mass moment of inertia of door about shaft axis, lb-sec^2-inch

The kinetic energy imparted to the door is given by

$$K.E. = \frac{I_m \omega^2}{2} = \frac{T_i^2}{2I_m} \qquad (6\text{-}19)$$

The strain energy absorbed by a circular shaft is given by

$$U_s = \frac{\pi L_s}{4G} (r_s \tau_s)^2 \qquad (6\text{-}20)$$

where

L_s = length of shaft, inches

G = shear modulus of shaft material, psi

r_s = radius of shaft, inches

τ_s = maximum shear stress in shaft, psi

Equating the kinetic energy of the rotating door to the strain energy in the shaft and solving for the shear stress yields

$$\tau_s = \frac{T_i}{r_s}\sqrt{\frac{2G}{\pi I_m L_s}} \qquad (6\text{-}21)$$

where

I_m = mass moment of inertia of door, lb-sec^2-inch

The computed shear stress in the shaft must be less than the dynamic shear stress of the shaft material, i.e.,

$$\tau_s < 0.55f_{dy}$$

6.6 SHIELD LINERS

6.6.1 Functional Requirements

The vented or porous nature of the suppressive shield wall creates a potential for explosive and/or flammable dust to filter into and accumulate within the interior of the shield wall. Removal of such accumulations can be extremely difficult. The dust could originate from an operation being performed inside the shield or from an exterior source. A means for sealing both the interior and exterior of the vented panels must be provided. One way to prevent the accumulation of dust in the shield wall is to provide liners which cover the inner and outer surfaces of the vented panels. Special attention should be given to the joints of the inner and outer liners to assure that the joints will not provide a route for explosive dust entry into the shield wall structure and that the joints themselves will not create an additional location for the accumulation of explosive dusts.

6.6.2 Design Considerations

The addition of liners to a suppressive shield could have an adverse effect on the performance of shields of certain groups. When shielding hazardous operations which involve pyrotechnic materials or propellants, the ventilating properties of the shield must be designed to minimize too rapid a pressure buildup within the structure. A liner for such applications must break or burn away so that ventilating properties are retained.

For explosive materials, the ventilation requirements are different. If the structure is designed to withstand the combined impulsive and quasi-static pressure loads, fragment impact and thermal effects, a continuous metal liner which remains in place during the incident is acceptable. Such continuous metal liners must not seal the shield sufficiently to prevent the products of combustion from venting, causing the shield to become a pressure vessel. Some suppressive shields are not designed to withstand the loads they would experience with a continuous metal liner. Liners for these shields must be designed so that the initial pressure blows out the liner to provide the venting properties designed into the shield. In all designs with liners which break away, care must be taken that hazardous secondary fragments are not produced outside the shield by pieces of the liner.

6.6.3 Recommended Configurations

a. Rigid Liners

Explosive materials can be confined within a suppressive shield with a rigid liner that does not allow venting of the airblast pressure only if the structure is designed to take the loads. These liners may be attached expeditiously with sheet metal screws to inside surfaces only.

The final installation of metal liners, such as in the Group 3 shield, should include a soft gasket material or caulking compound to seal the liner-panel interface and to prevent accumulation of explosive dust at inaccessible locations. Typical installation details are shown in Fig. 6-17.

b. Frangible Liners

A frangible plastic liner can be used on shields containing explosive materials without affecting their venting characteristics. A number of plastic film materials have been investigated as possible candidates for frangible internal liners. The material selected is Velostat plastic film. This material exhibits the following properties.

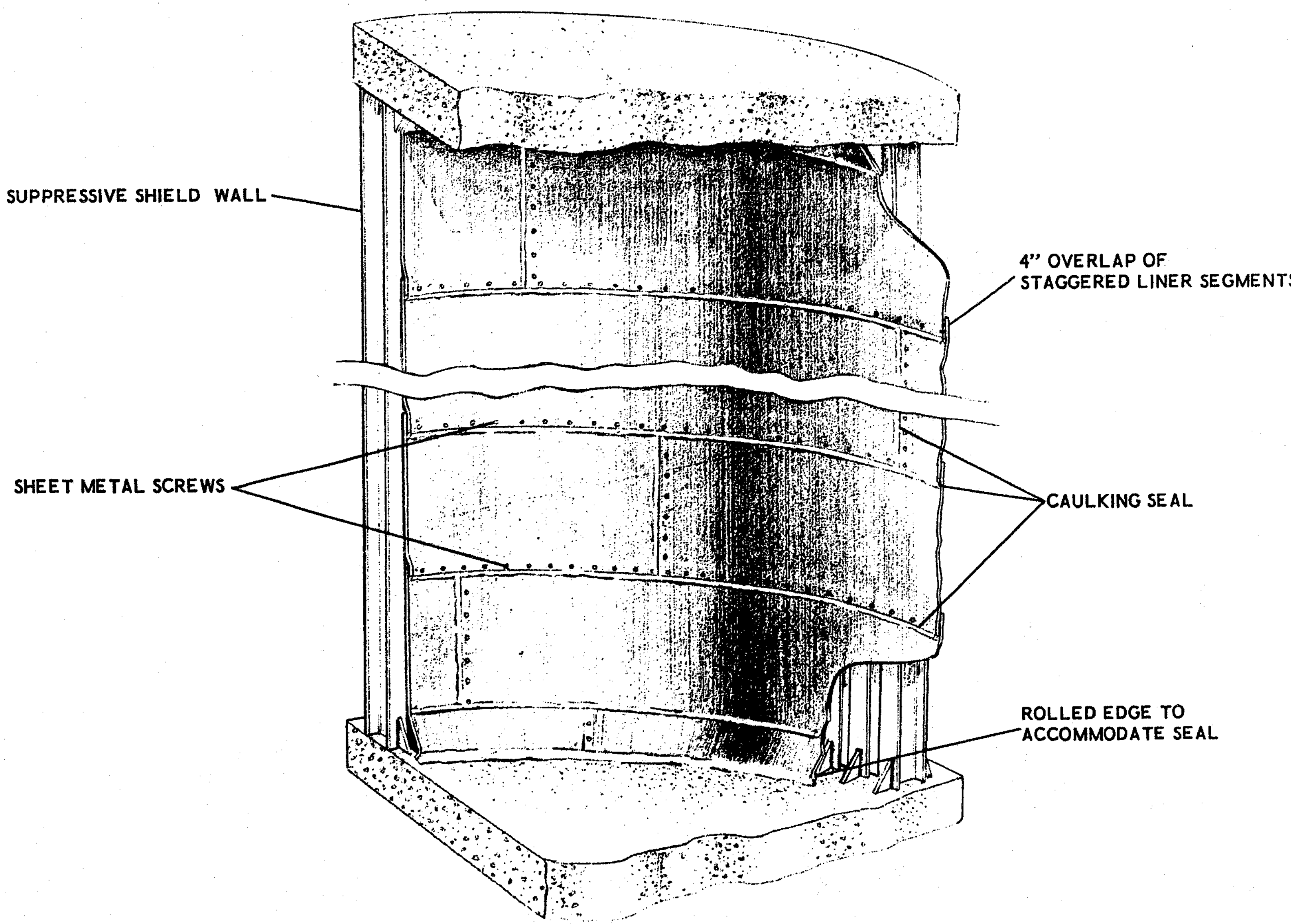


Figure 6-17. Typical Installation of Sheet Metal Liners

- Conductive
- Abrasive/tear resistant
- Disintegrates rapidly under flame
- Workable

Velostat or equal can be purchased with an adhesive applied to one side to allow easy attachment to the panel surface. Attachment can be accomplished as shown in Fig. 6-18.

Care must be taken to prepare the shield surface when installing adhesive-backed plastic liners so that a good bond is achieved. The material must be attached without wrinkles or gaps through which hazardous material can enter inaccessible regions of the panels.

For pyrotechnic materials, venting is essential to prevent shield damage. Tests indicate that the Group 5 shield requires internal and external liners fabricated from a lightweight material which will disintegrate, decompose, or fracture when a pyrotechnic material reacts in the shield. This will allow the rapidly expanding gases to bleed off as they are produced by the reaction, thus preventing excessive pressure buildup in the structure.

c. Summary

Table 6-2 summarizes the recommended internal and external liner systems for each of the safety approved shields. In all cases, a sealing system has been proposed which will preclude dust accumulation or leakage around the liner. This will also keep the extreme edges of the Velostat material from pulling loose and curling.

The liner material for external application requires the same characteristics as the internal liner material plus the additional requirement of being incapable of producing lethal or damaging fragments. The Velostat material meets all these requirements.

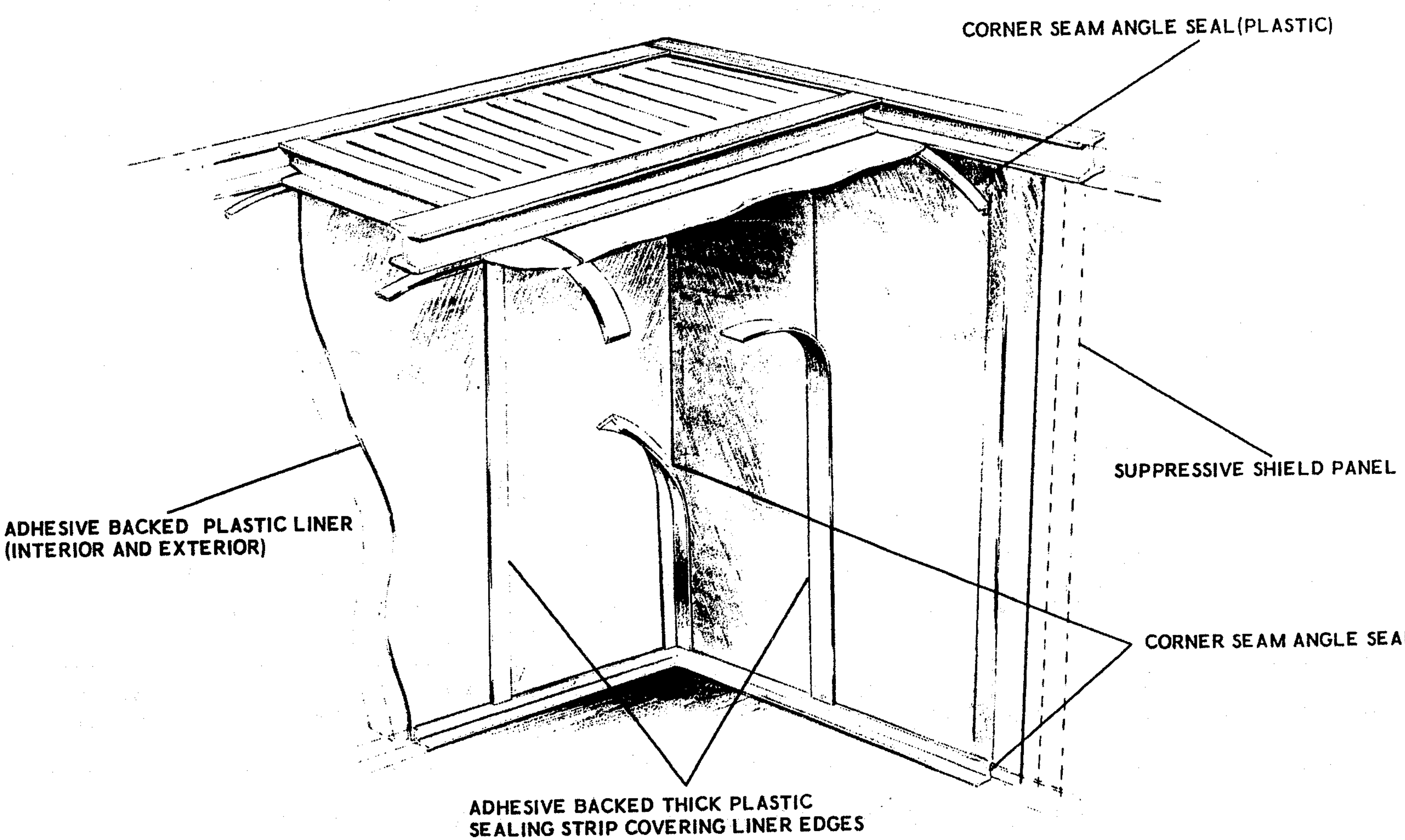


Figure 6-18. Typical Installation of Thin Plastic Liners

Table 6-2

SUMMARY OF PROPOSED LINERS FOR SUPPRESSIVE SHIELDS*

Shield Group	Interior Liner	Exterior Liner	Attachment Method	
			Internal	External
3	Sheet Metal	Velostat	Screws & Gasket	Adhesive & Cemented Plastic Strips
4	Velostat	Velostat	Adhesive & Cemented Plastic Strips	Adhesive & Cemented Plastic Strips
5	Velostat	Velostat	Adhesive & Cemented Plastic Strips	Adhesive & Cemented Plastic Strips
81-mm	Velostat	Velostat	Adhesive & Cemented Plastic Strips	Adhesive & Cemented Plastic Strips

* Velostat may be substituted for by an equivalent liner

6.7 ILLUSTRATIVE EXAMPLES

6.7.1 Bending in Box Structure Cover Plate

a. Given

The Group 3 shield has internal dimensions of 11.25 ft in diameter by 10 ft high. A utility penetration protective box attached to the wall of the shield has length, b_c; width, a_c; and cover thickness, t_c; dimensions of 20, 10 and 1 inches, respectively. The side plates are 8 inches high by 1 inch thick. Thicknesses were selected to correspond to the nominal wall thickness of the Group 3 shield. The box structure is fabricated from mild steel which has a modulus of elasticity, E, of 29 x 10^6 psi and a Poisson's ratio, ν, of 0.33. Its static yield strength is 36,000 psi.

b. Find

The response of the cover plate to an explosion of the proof charge weight of 45.7 lbs of 50-50 Pentolite.

c. Solution

Entries in Table A-3 show that the proof charge is equivalent to 51.6 lb of TNT. The sidewalls are at a scaled range of 1.511 ft/lb$^{1/3}$. At this range, Figs. 3-6 and 3-9 indicate the reflected impulse is 447 psi-msec, the peak reflected pressure equals 3200 psi, and the quasi-static pressure is 180 psi.

The side plates are bolted to the cover plate which coincides with the discussion in Section 6.2.3.c which assumes the connection to be a simple support. Therefore, the cover plate is analyzed as a plate simply supported along its four edges. The total mass of the plate is

$$M_t = (10)(20)(1)(0.29)/386$$

$$= 0.15 \text{ lb-sec}^2/\text{in}$$

Its moment of inertia per unit width is

$$I_a = t_c^3/12 = (1)^3/12 = 0.083 \text{ in}^4/\text{in}$$

For a width to length ratio of 0.5 and the assumed edge conditions, Table 5-4 gives a load-mass factor of 0.59. An expression for the spring constant for the plate is also obtained from Table 5-4.

$$K = 201EI_a/a_c^2 = 201(29 \times 10^6)(0.083)/(10)^2$$
$$= 4.84 \times 10^6 \text{ lb/in}$$

The fundamental frequency of vibration for the plate is obtained from Eq. 5-32, pg. 5-32.

$$\omega_N = \left[\frac{K}{K_{LM}M_t}\right]^{1/2} = \left[\frac{4.84 \times 10^6}{0.59 \times 0.15}\right]^{1/2}$$
$$= 7395 \text{ rad/sec}$$

The natural period for the fundamental mode is

$$T_N = \frac{2\pi}{\omega_N} = \frac{2(3.14)}{7395}$$
$$= 0.00085 \text{ sec}$$

Assuming a 10 percent increase in yield strength under dynamic loading, the plastic moment capacity of the cover plate is given by Eq. 5-3, pg. 5-7.

$$M_P = f_{dy}Z = 36{,}000(1.1)(1)^3/4$$
$$= 9900 \text{ in-lb/in}$$

The total moment capacity across the 10-inch width is

$$M_{Pfa} = 10(9900) = 99{,}000 \text{ in-lb}$$

Across the 20-inch length it is

$$M_{Pfb} = 20(9900) = 198{,}000 \text{ in-lb}$$

The maximum resistance of the simply supported rectangular plate is obtained from the equation in Table 5-4

$$R_m = \frac{1}{a_c}(12M_{Pfa} + 9.0M_{Pfb})$$

$$= \frac{1}{10}(12 \times 99{,}000 + 9.0 \times 198{,}000)$$

$$= 297{,}000 \text{ lb}$$

The duration of the triangular pressure pulse is given by Eq. 3-4, pg. 3-13.

$$t_r = t_1 = 2i_r/P_r$$

$$= 2 \times 0.447/3200$$

$$= 0.000279 \text{ sec}$$

and

$$t_o/T_N = 0.000279/0.00085$$

$$= 0.328$$

The duration of the reflected pressure pulse is short compared to the period of vibration of the plate and Eq. 5-54 is appropriate for determining its maximum response.

$$\left[\frac{C_1B/R_m}{\frac{T_N}{\pi t_1}\sqrt{2\mu-1}}\right]^2 + \left[\frac{C_2B/R_m}{1-\frac{1}{2\mu}}\right] = 1$$

For the given loading pulse,

$$C_1 = \frac{3200 - 180}{3200} = 0.944$$

$$t_1 = 0.000279 \text{ sec}$$

$$C_2 = 1.0 - C_1 = 1.0 - 0.944 = 0.056$$

$$B = (3200)(20)(10) = 640{,}000 \text{ lb}$$

By rearranging Eq. 5-54 the value of μ can be obtained:

$$\mu = \frac{\left[\dfrac{\dfrac{C_1 B}{R_m}}{\dfrac{T_n}{\pi t_1}}\right]^2 + 1}{2\left[1 - \dfrac{C_2 B}{R_m}\right]} = 3.07$$

Since μ is less than 6.0, the cover plate will survive the proof airblast in the Group 3 shield and experience a small plastic deformation. The maximum deformation is estimated using additional information from Table 5-4.

Since

$$R_m = KX_e$$

then

$$X_e = R_m/K$$

$$= 297{,}000/4.84 \times 10^6$$

$$= 0.061 \text{ inch}$$

and the maximum displacement is

$$X_m = \mu X_e$$

$$= 3.07 \times 0.061$$

$$= 0.187 \text{ inches}$$

6.7.2 Buckling of utility Box Side Members

a. Given

The structural and airblast parameters for this example are as described in Ex. 6.7.1.

b. Find

Check the sideplates of the utility penetration protective box for buckling resistance.

c. Solution

The dynamic reaction along the edge of the cover plate is calculated using information from Table 5-4. Recall from Ex. 6.7.1 that

$$R_m = 297{,}000 \text{ lb}$$

The airblast loading at the time of yield is assumed to be equal to the quasi-static overpressure. This assumption was investigated in Ex. 5.6.2 and 5.6.3 and found to be reasonable for impulsive type loadings combined with long duration quasi-static overpressures. In other problems where the time of maximum response, t_m, is less than the duration of the reflected pressure pulse, t_o, the pressure can be approximated as

$$P_{approx} = P_r\left(\frac{t_o - t_m}{t_o}\right)$$

For this example

$$F = P_{qs}A$$

$$= 180 \times 10 \times 20$$

$$= 36{,}000 \text{ lb}$$

From Table 5-4, the total reactions along the short and long sides of the cover plate are

$$V_a = 0.04F + 0.08R_m$$
$$= 0.04 \times 36{,}000 + 0.08 \times 297{,}000$$
$$= 25{,}200 \text{ lb}$$
$$V_b = 0.11F + 0.27R_m$$
$$= 0.11 \times 36{,}000 + 0.27 \times 297{,}000$$
$$= 84{,}150 \text{ lb}$$

The height of the sideplate, h, is given as 8 inches in Ex. 6.7.1. Its thickness, t_s, is 1 inch. The coefficient, K_b, to be used in Eq. 6-1, pg. 6-5 is selected from the table following the equation. For the long side a value of h/b_c equal to the value of K_b is 7.76. The critical buckling stress is obtained from Eq. 6-1.

$$\sigma_{cr} = \frac{K_b E}{1-\nu^2}\left[\frac{t_s}{b_c}\right]^2$$

$$= \frac{7.76 \times 29 \times 10^6}{1 - (0.33)^2}\left[\frac{1}{20}\right]^2$$

$$= 631{,}354 \text{ psi} > f_{dy}$$

The shear reaction of the cover plate along the long side is 84150 lb, thus the largest reaction is 4208 lb/in. The side members are 1 inch thick, and the compressive stress is 4208 psi. This stress is less than the yield strength of the material, and buckling is not a factor in the design of the side members.

6.7.3 <u>Shear in Shield Group 81-mm Split Collar at the Vacuum Line/Suppressive Shield Interface</u>

a. <u>Given</u>

The geometry of a typical waste disposal vacuum line is illustrated in Fig. 6-19. The vacuum line is shown passing through a Shield Group 81-mm wall panel.

The material in the bushing, split collars, and adapter fittings is mild steel; f_y = 36,000 psi, f_{dy} = 39,600 psi, $E = 29 \times 10^6$ psi, $\nu = 0.33$. The vacuum line is specified to have a nominal internal diameter of 2.0 inches. A 300-pound steel flanged 90 degree elbow has an inside diameter of 2.0 inches, a wall thickness of 0.25 inch, a flange diameter of 6.5 inches, a flange thickness of 0.875 inch, and a radius of curvature equal to 6.5 inches. Since the elbow thickness is less than the 1 inch required to defeat the fragment threat, an additional plate will be required to cover the region in front of the opening through the adapter fitting.

b. Find

Minimum thickness required for the split collar to (1) remain elastic until the elbow begins to yield in compression, and (2) satisfy the minimum thickness requirement specified to defeat the fragment threat.

c. Solution

If it is assumed that the vacuum line penetration is subjected to axial loads only, the compressive force developed in the elbow at the onset of yielding is calculated by multiplying the elbow cross sectional area, A, by the yield stress, f_{dy}. The cross sectional area is

$$\begin{aligned} A_{VL} &= \frac{\pi}{4}\,(D_o^2 - D_i^2) \\ &= \frac{\pi}{4}\,(2.5^2 - 2^2) \\ &= 1.77 \text{ in}^2 \end{aligned}$$

and the compressive force is

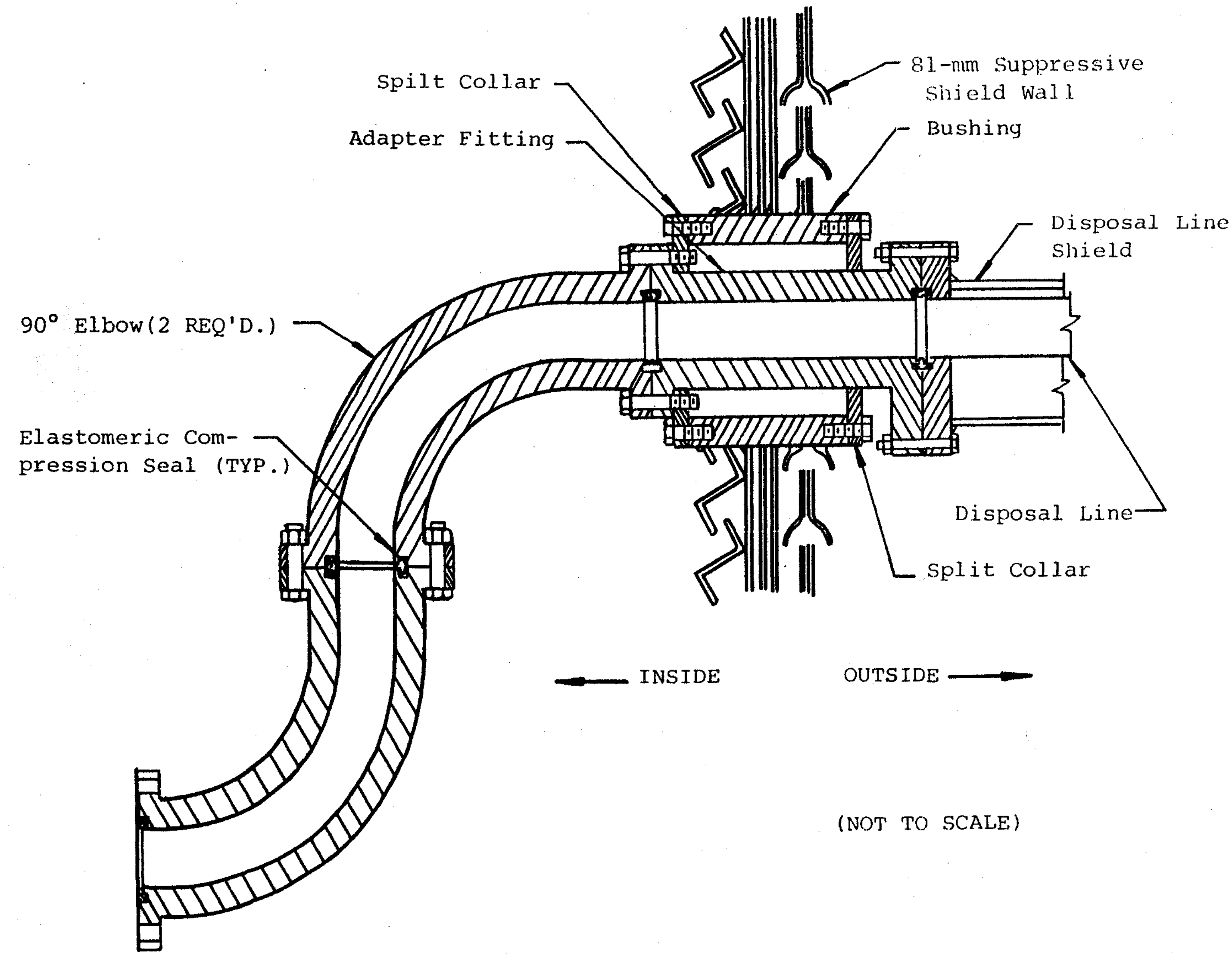


Figure 6-19. Waste Disposal Line Entry Into Suppressive Shield

$$F = A_{VL} f_{dy}$$
$$= 1.77 \times 39{,}600$$
$$= 70{,}092 \text{ lb}$$

The shear area, A_{sh}, through the collar is

$$A_{sh} = \pi D_{flange} t$$

where t is the split collar thickness. The allowable shear stress, τ_s equals 0.55 f_{dy}, or 21,780 psi, and the allowable shear force is

$$F_{allowable} = A_{sh} \tau_s$$

Equating the applied force to the allowable force and substituting the allowable stress yields the required shear area and, hence, the split collar thickness.

$$A_{sh} = F/\tau_s$$
$$= 70{,}092/21{,}780$$
$$= 3.2 \text{ in}^2$$
$$t = 3.2/(3.14 \times 6.5)$$
$$= 0.16 \text{ inch}$$

Half of the nominal wall thickness for the Group 81-mm shield equals 0.5 inch. Therefore, the minimum recommended thickness for the split collars is 0.5 inches to defeat fragments.

6.7.4 Stress in Group 3 Shield External Disposal Line Shield Caused by Munition Explosion

a. Given

A waste disposal vacuum line is installed on the Group 3 shield considered in the first 2 example problems in this chapter. The vacuum line performance requirements dictate that the vacuum line should be about 2.0 inches and the vacuum line shield about 4 inches in diameter. The tubing selected for the shield measures 4.5 inches outside diameter by 0.188 inch wall thickness. Tubing material is 6061-T6 extruded and drawn aluminum tubing; $f_y = 35{,}000$ psi, $\nu = 0.33$, $E = 10 \times 10^6$ psi, $\rho = 0.098$ lb/in^3.

b. Find

Verify that the tensile stress in the Group 3 external vacuum line shield caused by an accidental explosion equal to the proof charge weight of 45.7 lbs of 50-50 Pentolite will not exceed its yield strength.

c. Solution

The mass of the tube per unit of surface area is

$$m = \frac{t\rho}{g}$$

$$= \frac{(0.188)(0.098)}{386}$$

$$= 4.77 \times 10^{-5} \text{ lb-sec}^2/\text{in}^3$$

The natural period of vibration of the vacuum line in the extensional mode is calculated using Eq. 5-23, pg. 5-26.

$$T_N = 2\pi\sqrt{\frac{mR^2}{Et}}$$

$$= 2\pi\sqrt{\frac{4.77 \times 10^{-5} \times (2.156)^2}{10 \times 10^6 \times 0.188}}$$

$$= 6.82 \times 10^{-5} \text{ sec}$$

The critical location for stress in the disposal line is at a point just outside of the suppressive shield wall. The interior radius of the suppressive shield is 5.625 ft. Assuming a wall thickness of 3 inches the radius to a point on the outer surface of the shield is

$$R = 5.625 + \frac{3}{12} = 5.875 \text{ ft}$$

As noted in a previous example, 45.7 lbs of 50-50 Pentolite is equivalent to 51.6 lbs of TNT, therefore, the scaled distance is

$$Z = \frac{R}{W^{1/3}} = \frac{5.875}{(51.6)^{1/3}}$$

$$= 1.578 \text{ ft/lb}^{1/3}$$

From Fig. 3-3, the peak overpressure is

$$P_{so} = 400 \text{ psi}$$

and the scaled positive impulse is

$$0.018 \text{ psi-sec/lb}^{1/3}$$

The impulse is

$$i_s = 0.018(51.6)^{1/3} = 0.067 \text{ psi-sec}$$

The effective duration of an equivalent triangular pulse is

$$t_o = \frac{2i_s}{P_{so}} = \frac{2(0.067)}{400} = 0.000335 \text{ sec}$$

and

$$\frac{t_o}{T_N} = \frac{0.000335}{0.0000682} = 4.91$$

Compute the maximum resistance of the shield using Eq. 6-6, pg. 6-22

$$r_m = f_{dy}t/R_i = 35{,}000(0.188)/2.06$$

$$= 3194 \text{ psi}$$

Use Eq. 5-47, pg. 5-55 to determine the required maximum resistance for $\mu = 1$. Substituting $\mu = 1$ in

$$\frac{P_r}{r_m} = \frac{T_N}{\pi t_o}\sqrt{2\mu-1} + \frac{1 - \frac{1}{2\mu}}{1 + 0.7\,\frac{T_N}{t_o}}$$

$$\frac{P_r}{r_m} = \frac{0.0000682}{3.14(0.000335)} \sqrt{2(1) - 1} + \frac{1 - \frac{1}{2(1)}}{1 + 0.7\left(\frac{0.0000682}{0.000335}\right)}$$

$$= 0.502$$

or the required r_m is

$$r_m = \frac{400}{0.502} = 796 \text{ psi}$$

Since 3194 psi is provided, the shield will remain elastic under the airblast generated by an internal explosion of 45.7 lbs of 50-50 Pentolite.

6.7.5 Stress in Group 3 Shield Disposal Line Shield Caused by an Airborne Dust Explosion

a. Given

The vacuum disposal line shield for the Group 3 shield considered in the previous problem experiences an internal airblast pressure due to the detonation of airborne dust particles. Without specific information as to the actual concentration levels and types of HE dust that might be encountered in the vacuum line, the most severe condition is assumed. The worst explosion shown in Table 6-1 will result from a concentration of 1.0 oz/cu ft of Comp. D (ammonium picrate). From Table 6-1,

$$\text{max pressure} = P = 141 \text{ psi}$$

$$\text{max rate of pressure rise} = r_p = 8800 \text{ psi/sec}$$

b. Find

Investigate tensile stress in the Group 3 external disposal shield caused by an explosion of airborne HE dust.

c. Solution

The loading pulse rise time is calculated from Eq. 6-7, pg. 6-23.

$$t_r = \frac{P}{r_p}$$

$$= 141/8800$$

$$= 0.016 \text{ sec}$$

The natural period of the disposal line was calculated in Ex. 6.7.4 as 6.82×10^{-5} sec, yielding a ratio of t_r/T_N of 234, a very long rise time relative to the natural period. The maximum resistance for the thin wall cylinder is approximated using Eq. 6-6, pg. 6-22.

$$r_m = f_{dy}t/R_i$$

$$= 35{,}000 \times 0.188/2.06$$

$$= 3194 \text{ psi}$$

The ratio of peak pressure to element resistance is

$$r_m/P_r = 3194/141$$

$$= 22.6$$

The values of r_m/P_r and t_r/T_N are well off the chart shown in Fig. 6-9, but they are off in the direction that indicates the ductility ratio will be much less than unity. Hence,

$$\mu << 1$$

and the vacuum line shield selected is acceptable.

This problem could also have been solved using the approach outlined in Ex. 6.7.4 where the actual r_m is shown to be greater than that required for elastic response.

6.7.6 Stress in Disposal Line Shield Caused by Dust Sediment Explosion

a. Given

The largest accumulation of explosive dust shown in Fig. 6-10 is assumed to be present and detonate in the disposal line. The disposal line shield considered in this and the previous two examples is 4.12 inches inside diameter by 0.188 inch wall thickness 6061-T6 extruded and drawn aluminum tubing.

b. Find

Determine the response of the Group 3 external disposal line shield to an explosion of HE dust sediment in the vacuum disposal line.

c. Solution

The largest amount of dust estimated to collect on the bottom surface of the vacuum line is shown as 0.10 oz/inch in Fig. 6-10. The internal radius for the vacuum line shield is 2.06 inches, therefore, the scaled range is

$$Z = R/W^{1/3}$$

$$= (2.06/12.0)/(0.1/16.0)^{1/3}$$

$$= 0.932 \text{ ft/lb}^{1/3}$$

From Fig. 3-6, the following values are obtained for peak positive reflected pressure and positive reflected impulse.

$$P_r = 8000 \text{ psi}$$

$$i_r/W^{1/3} = 0.23$$

$$i_r = 0.23 \times (0.1/16.0)^{1/3}$$

$$= 0.0424 \text{ psi sec}$$

The duration of the equivalent triangular representation for the reflected pressure/time curve is

$$t_o = 2 \times i_r/P_r$$

$$= 2 \times 0.0424/8000$$

$$= 1.06 \times 10^{-5} \text{ sec}$$

From Ex. 6.7.4, the natural period of vibration for the chosen vacuum line shield is $T_N = 6.82 \times 10^{-5}$ sec. The ratio

$$t_o/T_N = \frac{1.06 \times 10^{-5}}{6.82 \times 10^{-5}}$$

$$= 0.16$$

indicates that the load is impulsive. The maximum resistance provided by the tube shield is obtained from Eq. 6-6, pg. 6-22.

$$r_m = f_{dy} t/R_i$$

$$= 35{,}000 \times 0.188/2.06$$

$$= 3194 \text{ psi}$$

The required maximum resistance that the tubing must develop to remain elastic is obtained from Eq. 5-43, pg. 5-54 by setting the ductility ratio equal to unity.

$$r_m = P_r \left[\frac{\pi t_o}{T_N \sqrt{2\mu - 1}} \right]$$

$$= 3200 \left[\frac{\pi \times 1.06 \times 10^{-5}}{6.82 \times 10^{-5} \sqrt{2-1}} \right]$$

$$= 1560 \text{ psi}$$

Since the required maximum resistance is less than that provided, the disposal line shield will remain elastic and is acceptable. In those cases where r_m provided is less than r_m required to remain elastic and the load is impulsive, the peak response can be calculated in terms of the ductility ratio by using Eq. 5-45 or 5-47, pg. 5-55.

6.7.7 Fragment Hazard From Detonation of Explosive Dust Sediment in Disposal Line

a. Given

The Group 3 disposal line and disposal line shield are subjected to an explosion of dust sediment in the disposal line.

b. Find

Evaluate the ability of the disposal line shield to stop fragments produced by the explosion of Comp B dust sediment in the disposal line.

c. Solution

From Fig. 6-10, it is estimated that the maximum weight of explosive dust per inch of disposal line is

$$W = 0.10 \text{ oz/in}$$

The interior radius of the disposal line is 0.94 inch and it is assumed that the density of the explosive dust sediment is $\rho_e = 0.0289 \text{ lb/in}^3$. Substituting these values in Eq. 6-9, pg. 6-30,

$$W = \rho_e \left[\frac{R_1^2(\theta_e - \sin\theta_e)}{2}\right]$$

$$\frac{0.1}{16} = 0.0289 \left[\frac{(0.94)^2(\theta_e - \sin\theta_e)}{2}\right]$$

it is found that $\theta_e \doteq 1.4858$ radians.

The density of aluminum is taken to be 0.10 lb/ in^3. The outer radius of the disposal line is 1.0 inch. The weight of metal per inch of aluminum disposal line in contact with the dust sediment is obtained from Eq. 6-8, pg. 6-28.

$$W_c = \frac{\rho_m}{2}\theta_e\left[R_o^2 - R_i^2\right] = \frac{0.1(1.4858)}{2}\left[(1.0)^2 - (0.94)^2\right]$$

$$= 0.0086 \text{ lb/in} = 0.1384 \text{ oz/in}$$

The empirical constant $\sqrt{2E'}$ is taken as 8900 fps for Comp B, and the fragment velocity is obtained from Eq. 6-10, pg. 6-30.

$$v_o = \sqrt{2E'}\sqrt{\frac{3}{1 + (5W_c/W) + 4(W_c/W)^2}}$$

$$= 8900\sqrt{\frac{3}{1 + \left(\frac{5 \times 0.1384}{0.1}\right) + 4\left(\frac{0.1384}{0.1}\right)^2}}$$

$$= 3905 \text{ fps}$$

The thickness of the fragment is taken equal to the thickness of the vacuum disposal line shield. The side dimensions of the fragment are obtained from Eq. 6-13, pg. 6-32.

$$L = R_i\theta_e = 0.94(1.4858) = 1.3967 \text{ inches}$$

The weight of the fragment is obtained from Eq. 6-14, pg. 6-32.

$$W_s = \rho_m tL^2 = 0.1(0.06)(1.3967)^2 = 0.0117 \text{ lb}$$

The presented area of the fragment is given by Eq. 6-15, pg. 6-32.

$$A_p = L^2 = (1.3967)^2 = 1.95 \text{ in}^2$$

From Table 3-5 for $L/t > 5$,

$A_o = 1261$ $m = 0.427$ $n = 0.647$

Substituting in Eq. 6-12, pg. 6-31, the thickness of vacuum line shield required to stop the fragment is

$$t_t = \left[\frac{v_1\sqrt{W_s}}{A_o A_p^m}\right]^{1/n} = \left[\frac{3905\sqrt{0.0117}}{1261(1.95)^{0.427}}\right]^{1/0.647}$$

$$= 0.119 \text{ inch}$$

From Ex. 6.7.4, the shield wall thickness is 0.188 inch, so the shield should contain the fragment. If an edge-on impact is assumed, a shield thickness of 0.95 inch is required for containment.

6.7.8 Determine the Area of the Environmental Conditioning Exhaust Stack for the Milan 81-mm Suppressive Shield

a. Given

The Milan 81-mm suppressive shield has inside dimensions of 14 feet wide by 14 feet long by 12.4 feet high. The design charge weight for incident and reflected overpressure and impulse is 4.53 lb TNT.

b. Find

The exhaust stack area required to provide two complete air changes per hour at a maximum velocity of 400 ft/min.

c. Solution

The required exhaust stack area is

$$A_{ex} = Q/v_a$$

where

$$Q = VN_a$$

and

Q = air flow rate, ft^3/min

V = shield internal volume, 2430.4 ft^3

N_a = number of changes per minute, 0.0333

v_a = air flow velocity, 400 ft/min

Substituting, the required area is

$$A_{ex} = \frac{2430.4(0.0333)}{400} = 0.2 \text{ ft}^2 = 29.1 \text{ in}^2$$

6.7.9 Determination of Exhaust Stack Height

a. Given

A frangible structure is located immediately adjacent to the Milan 81-mm suppressive shield described in the previous problem. The height to the roof of the frangible structure is the same as that of the shield.

b. Find

The height of the exhaust stack required to limit the overpressure on the roof of the frangible structure to 0.3 psi.

c. Solution

The required stack height is determined from Eq. 6-16, pg. 6-36.

$$P_{so} = 290\left[\frac{A_{ex}}{V^{2/3}}\right]^{0.401}\left[\frac{W^{1/3}}{R}\right]^{1.496}$$

where

P_{so} = peak overpressure = 0.3 psi

A_{ex} = exhaust stack area = 0.2 ft^2

V = internal volume of shield = 2430.4 ft^3

W = charge weight = 4.53 lb

R = distance from exhaust exit, ft

Rearranging and substituting,

$$R^{1.496} = \frac{290}{0.3}\left[\frac{0.2}{(2430.4)^{2/3}}\right]^{0.401}\left[(4.53)^{1/3}\right]^{1.496}$$

$$= 133.986$$

and

$$R = 26.41 \text{ ft}$$

Therefore, the minimum stack height to limit overpressure on the roof of the frangible structure to 0.3 psi is 26.4 feet.

6.7.10 Stress in Environmental Conditioning Exhaust Stack

a. Given

The exhaust stack of the Milan 81-mm suppressive shield described in previous problems is a steel tube with the following properties.

$$E = 29 \times 10^6 \text{ psi}$$

$$\nu = 1/3$$

$$\rho = 0.286 \text{ lb/in}^3$$

$$f_y = 36{,}000 \text{ psi}$$

$$f_{dy} = 39{,}600 \text{ psi}$$

b. Find

The stress in the exhaust stack caused by an explosion inside the shield.

c. Solution

From Ex. 6.7.11, the exhaust stack requires a cross sectional area of 29.1 in^2. The inside radius is

$$R_i = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{29.1}{3.14}} \simeq 3.0 \text{ inches}$$

Use a 6.25 inch O.D. tube with a 0.125 inch wall. The natural period of the tube is given by Eq. 5-23, pg. 5-26.

$$T_N = 2\pi\sqrt{\frac{mR^2}{Et}}$$

Since

$$m = \frac{t\rho}{g}$$

Equation 5-23 can be written in the form

$$T_N = 2\pi\sqrt{\frac{\rho R^2}{Eg}}$$

where

ρ = density of tube material, 0.286 lb/in^3

R = mean radius of tube, 3.0625 inches

E = modulus of elasticity, 29 x 10^6 psi

g = gravitational acceleration, 386 in/sec^2

Substituting

$$T_N = 2\pi\sqrt{\frac{0.286(3.0625)^2}{29(10)^6(386)}}$$

$$= 0.000097 \text{ sec}$$

The peak overpressure, P_{so}, and positive impulse, i_s, at a point just outside the suppressive shield is obtained from Fig. 3-3. For a scaled distance

$$Z = R/W^{1/3} = 7.5/4.53^{1/3} = 4.53 \text{ ft/lb}^{1/3}$$

the peak overpressure, P_{so}, is 30 psi. The scaled positive impulse is 0.011 psi-sec/lb$^{1/3}$. The positive impulse is

$$i_s = 0.011W^{1/3} = 0.011(4.53)^{1/3} = 0.0182 \text{ psi-sec}$$

Therefore, the pulse duration of an equivalent triangular pulse is

$$t_o = \frac{2i_s}{P_{so}} = \frac{2(0.0182)}{30} = 0.00121 \text{ sec}$$

The ratio of the pulse duration to the natural period of the tube is

$$\frac{t_o}{T_N} = \frac{0.00121}{0.000097} = 12.5$$

Since the ratio is greater than 10, the required maximum resistance of the exhaust stack is given by Eq. 5-37, pg. 5-53.

$$r_m = P_{so}\left[\frac{2\mu}{2\mu-1}\right] = 30\left[\frac{2\mu}{2\mu-1}\right]$$

For the elastic case, $\mu = 1$. Therefore,

$$r_m = 30\left[\frac{2}{1}\right] = 60 \text{ psi}$$

The membrane stress in the exhaust stack is

$$\sigma = r_m R_i/t = \frac{60(3)}{0.125} = 1440 \text{ psi}$$

This stress is well below the dynamic yield stress of the tube. No further analysis is necessary.

6.7.11 Stress in the Shaft of the Rotary Product Door Caused by the Accidental Detonation of Munitions During Production

a. Given

The rotary product door that has been conceived and tested for the 81-mm shield group is illustrated pictorially in Fig. 6-16. It is desired to analytically investigate the response of the product door to an accidental detonation equal to the Prototype 81-mm Shield proof charge. Maximum torque will be transferred to the product door when the munition opening is coincident with a pocket in the rotating door. The area of the product door, A_d, exposed to the airblast is 38.9 in^2. The effective moment arm, r_d, from the center of rotation to the centroid of the area A_d is 4.32 inches. Analysis of the rotary product door prototype has revealed that the moment of inertia, I_m, of the assembly is about 6.23 in-lb-sec^2. The shaft is constructed of 1025 carbon steel with an allowable yield stress, f_y, of 36,000 psi, a modulus of elasticity, E, of 29 x 10^6 psi, and a Poisson ratio, ν, of 0.333. The shaft radius, r_s, is 0.75 inch and its length, L_s, is 6.0 inches.

b. Find

The shear stress in the shaft of a rotary product door in the Prototype 81-mm Shield caused by the detonation of a proof charge.

c. Solution

The proof charge is equivalent to 125 percent of the design charge listed in Table A-8a.

$$W_{TNT} = 7.24 \times 1.25$$

$$= 9.05 \text{ lb}$$

Scaled range to the sidewall located 7.0 feet from the shield centerline is

$$Z = \frac{R}{W^{1/3}}$$

$$= \frac{7}{(9.05)^{1/3}}$$

$$= 3.36 \text{ ft/lb}^{1/3}$$

The scaled reflected impulse is read from Fig. 3-6 as

$$i_r/W^{1/3} = 4.6 \times 10^{-2} \text{ psi-sec/lb}^{1/3}$$

Hence,

$$i_r = 4.6 \times 10^{-2} \times (9.05)^{1/3}$$

$$= 0.096 \text{ psi-sec}$$

The angular impulsive load, T_i, is calculated from Eq. 6-17, pg. 6-42.

$$T_i = i_r A_d r_d$$

$$= 0.096 \times 38.9 \times 4.32$$

$$= 16.13 \text{ lb-sec-in}$$

The modulus of rigidity, G, is a function of the modulus of elasticity, E, and calculated as follows.

$$G = \frac{E}{2(1 + \nu)}$$

$$= \frac{29 \times 10^6}{2(1 + 1/3)}$$

$$= 10.9 \times 10^6 \text{ psi}$$

The shear stress can now be calculated from Eq. 6-21, pg. 6-44.

$$\tau_s = \frac{T_i}{r_s}\sqrt{\frac{2G}{\pi I_m L_s}}$$

$$= \frac{16.13}{0.75}\sqrt{\frac{2 \times 10.9 \times 10^6}{\pi \times 6.23 \times 6}}$$

$$= 9{,}300 \text{ psi}$$

The allowable shear stress as indicated in Chapter 4 is

$$\tau = 0.55 f_{dy}$$

$$= 0.55 \times 1.1 \times 36{,}000$$

$$= 21{,}780 \text{ psi}$$

The allowable shear stress for the material is greater than the expected shear stress. Therefore, the shaft should not yield.

6.8 LIST OF SYMBOLS

a_c	Width of cover plate (inches)
A_d	Door area (in^2)
A_{ex}	Exhaust duct area (ft^2)
A_o	Equation constant
A_p	Area of fragment (in^2)
A_{SHC}	Collar area resisting shear (in^2)
A_{VL}	Cross section area of vacuum line (in^2)
b_c	Length of cover plate (inches)
B	Peak total load (lbs)
E	Modulus of elasticity (psi)
f_{dy}	Dynamic tensile yield stress (psi)
G	Modulus of rigidity (psi)
h	Height of side plate (inches)
i_r	Reflected pressure impulse (psi-sec)
i_s	Positive incident impulse (psi-sec)
I_m	Mass moment of inertia of door ($lb\text{-}sec^2\text{-}inch$)
k	Number of different types of plates in shield panel
K_b	Plate buckling constant
K.E.	Kinetic energy (in-lb)
ℓ,L	Length (inches)
L_1	Length of transverse mounted protective box side plate (inches)
L_2	Length of longitudinal mounted protective box side plate (inches)
L_S	Length of shaft, inches
m	(1) Mass per unit surface area of cylinder ($lb\text{-}sec^2/in^3$) (2) Equation constant

n	(1) Number of different types or sizes of panel members (2) Equation constant
N_a	Number of air changes per minute
P_r	Peak reflected overpressure (psi)
P_{ro}	Peak overpressure (psi)
P_s	Incident pressure outside stack (psi)
P_{so}	Peak positive incident pressure (psi)
Q	Air flow rate (ft^3/min)
r_d	Radius from center of impulse load to center of door rotation (inches)
r_m	Maximum unit resistance (psi)
r_p	Rate of pressure rise (psi/sec)
r_s	Radius of shaft (inches)
R	Average radius (inches)
R_i	Inside radius (inches)
R_m	Maximum resistance (lbs)
R_o	Outside radius (inches)
t	Wall thickness (inches)
t_c	Thickness of cover plate (inches)
t_o	Duration of positive pressure pulse (sec)
t_r	Duration of positive reflected pressure (sec)
t_s	Thickness of side plate (inches)
t_t	Thickness of material being penetrated (inches)
T_i	Angular impulsive load (lb-sec-in)
T_N	Natural period of vibration (sec)

U_s	Torsional shear strain energy (in-lb)
v_a	Air flow velocity (ft/min)
v_o	Initial fragment velocity (ft/sec)
v_L	Minimum velocity for penetration (ft/sec)
V	(1) Volume (ft^3) (2) Dynamic reaction at end or edge of symmetric element (lbs)
V_B	Total dynamic reaction along one long edge, b (lbs)
V_C	Dynamic load along transverse plate (lbs)
V_L	Dynamic load along longitudinal plate (lbs)
W	Charge weight of explosive (lbs)
W_c	Weight of unit length of tube (lbs)
W_s	Striking weight of fragment (lbs)
W_T	Weight of explosive per unit length of tube (oz/in)
X_e	Elastic limit displacement (inches)
X_m	Maximum displacement (inches)
Z	Scaled distance ($ft/lb^{1/3}$)
θ_e	Angle which explosive subtends (radians)
μ	Ductility ratio
ν	Poisson's ratio
ρ_e	Density of explosive (oz/in^3)
ρ_m	Density of tube material (lb/in^3)
σ	Stress (psi)
σ_b	Compressive stress in side plate (psi)
σ_{cr}	Critical buckling stress (psi)
τ_{cp}	Shear stress in cover plate (psi)
τ_s	Dynamic shear yield stress (psi)
τ_{SP}	Average shear stress around perimeter of protective box (psi)
ω	Angular velocity (radians/sec)
$\sqrt{2E'}$	Gurney energy constant (ft/sec)

6.9 REFERENCES

6-1 Joint Munitions Effectiveness Manual, FM101-62-3, Manual of Fragmentation Data, 15 September 1973. (C-XGDS-3)

6-2 Roark, R.J. and Young, W.C., Formulas for Stress and Strain, McGraw-Hill Book Co., New York, N.Y., 5th Edition, 1975. (U)

6-3 Schroeder, F.J., Kachinski, R.L., Schnapfe, R.W., Koger, D.M., McKivrigan, J.L. and Jezek, B.W., Engineering Design Guidelines, Drawings and Specifications for Support Engineering of Suppressive Shields, EM-CR-76097, Edgewood Arsenal, Aberdeen Proving Ground, Md., December 1976. (U)

6-4 Hubich, H.O. and Kachinski, R.L., Explosive Waste Removal Systems for Suppressive Shields, EM-CR-76002, Edgewood Arsenal, Aberdeen Proving Ground, Md., August 1975. (U)

6-5 Nagy, J., et al, Explosibility of Miscellaneous Dusts, United States Department of the Interior, Bureau of Mines, Report of Investigations 7208, December 1968. (U)

6-6 Crawford, R.E., Higgins, C.J. and Bultmann, E.H., The Air Force Manual for Design and Analysis of Hardened Structures, AFWL TR 74-102, Air Force Weapons Laboratory, Kirtland AFB, N.M., October 1974. (U)

6-7 Keenan, W.A. and Tancreto, J.E., Blast Environment from Fully and Partially Vented Explosions in Cubicles, Technical Report R828, Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California, November 1975. (U)

6-8 Safety Manual, AMCR 385-100, Headquarters, U.S. Army Materiel Command, Alexandria, Va., Latest Edition. (U)

6-9 Seely, F.B. and Ensign, N.E., Analytical Mechanics for Engineers, John Wiley & Sons, Inc., New York, N.Y., 3rd Edition, 1948. (U)